Norwalk, Connecticut

ENGINEERING & OPTICAL DIVISION — THE PERKIN-ELMER CORPORATION

ENGINEERING REPORT NO. 52[illegible]-A

24" High Acuity Panoramic Camera-Type E-2

COPY NO. ______ DATE (Rev. 6/18/58)

PREPARED FOR Wright Patterson Air Force Base, Dayton, Ohio

The attached proposal from Chicago Aerial Industries has a minor redundancy in respect to the power requirement. Their proposal calls for a power requirement of 300 watts. This includes some power which is necessary to operate the camera drive itself, which is in excess of the power required for the Chicago Aerial Industries portion of the work. Actually the power requirement is closer to 100 watts.

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ABSTRACT

This proposal outlines the design approach which would most adequately encompass the specifications and performance requirement for the Panoramic Camera described in the proposal request WCLR-481.

The design advocated herein is based on the use of one scanning element in the form of a double-dove prism, and two separate optical paths. The primary feature of the design is non-intermittent operation and continuous scan, with nearly 100% duty cycle of the scan prism. Special attention has been paid to the realistic and practical methods of synchronization necessary in such a scanning system and to the reliability and durability of the finished product. In the development of the configuration, weight was given constant consideration, and particular emphasis was placed on simplification of the stabilization system.

INTRODUCTION

In our technical approach to this development, we have been guided by two basic considerations: 1.) the Air Force's requirements as enunciated by the specification and the bidders' briefing, and 2.) the state of the art which we believe is achievable during the available time period.

In recent years, advances in the technology of film manufacture, in optical design, in stabilization techniques, and various other aspects of aerial photographic system design have made possible great strides in the improvement of photographic systems. It is now possible to design and manufacture systems which are capable of gathering a great deal more information per pound of equipment weight than was possible even a few years ago.

An aerial photographic system is always slightly poorer than its weakest link. If one starts out with a given resolving power in airborne use as a goal, them the resolving power of the film and lens must be greater than that goal. In addition, the stabilization must be done to an accuracy which does not degrade the resolution of the lens-film combination to any large degree. The image motion compensation must be held within small limits. The shutter,

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if one is employed, must not degrade the image to any appreciable extent. In short, the degradation of the various components must be minimized.

In examining the specifications for this particular system, it becomes evident that a great deal of emphasis must be placed on the mechanical design in order to avoid excessive degradation of the inherent resolving power of the lens-film combination. There are four fundamental points which must be kept in mind in designing this system:

1. The optical system must be of extremely high quality.
2. The film used must not seriously limit the inherent resolving power of the lens.
3. The mechanical aspects of this system, such as film transport, image motion compensation, stabilization, etc., must be "quiet", that is, have very little vibration.
4. The entire system must be reliable and must be controllable by the operater in an easily comprehended manner.

Perkin-Elmer has had a rather unique experience in the design of high acuity photographic systems, particularly panoramic. The E-1 panoramic camera, designed and built by Perkin-Elmer, produced results which at the time demonstrated a significant advance in the state of the art of aerial photography. More recently we have designed and produced a number of small panoramic cameras, known as the Model 501, which are producing excellent results in flight. With these cameras we have regularly obtained results on film in the air well in excess of 40 l/mm.

We feel that our own experience at Perkin-Elmer in the design and manufacture of high acuity optical systems and in the design and manufacture of panoramic cameras is most applicable to this development. Our reputation has been built on our capability in organizing and managing such complex opto-electronic mechanical systems. We do feel that there are other firms whose experience in certain aspects of photographic system development could be usefully brought to bear on this program. We believe that by augmenting our own experience with the experience of The Aeroflex Corporation and Chicago Aerial Industries, Inc., we will be able to bring to this development as fine a group of technical specialists as could be assembled. Aeroflex has had considerable experience in the area of stabilization of photographic systems. Chicago Aerial Industries has also had enviable experience in the area of camera systems control.

We therefore propose to assemble a team consisting of Perkin-Elmer who will act as prime contractor and system manager; The Aeroflex Corporation who will develop the stabilization equipment and the thermal barrier; and Chicago Aerial Industries, Inc., who will develop the camera control system. We believe that the combined experience of all three companies will enable Perkin-Elmer to produce a panoramic system which will significantly advance the state of the art of daylight photographic reconnaissance.

DISCUSSION - SCANNING SYSTEMS

General

In considering the specifications of the E-2 camera, special consideration has to be given to almost all the factors which hitherto have been considered only separately, due to the limited scope of previous requirements. This consolidation of ideas has resulted in the reevaluation of several basic design principles. Foremost among these principles is the theory of a continuously moving film through the film plane, as opposed to intermittent film transport (stepping between exposures). This consideration has developed into a concept in which all moving parts are continuously functioning to eliminate starting or stopping shocks which usually result in image degradation and resolution loss. The high accuracy of the stabilization requires that it be considered at the outset as part of the integral configuration design, instead of as an accessory, as is so often the case. Toward this end, the optical equipment design should be such as to locate the center of gravity in space, affording access for a stabilization system knuckle joint suspension instead of conventional gimbals.

An important asset of such a design approach is the great saving of weight and size. Symmetry of the configuration, as well as size and weight, are salient factors which must govern design. Simplicity of design, as well as a minimum quantity and size of optional elements, especially mirrors which are prone to vibration effects, is important. A rational approach is necessary with regard to ease of fabrication, assembly and alignment, with particular attention paid to a system design which has its critical dimensions and characteristics built in. And, finally, the aspect of ease of operation and maintenance has to be kept in mind.

With these principles as guides, system design was attempted. Throughout the study, many different configurations developed which were eventually discarded, but which brought out features ultimately employed as part of the final design approach.

Specific

The requirement of continuously moving film and scanning element, when a scanning prism is used, calls for a prism duty cycle approaching 100%. Since, to achieve a 180^{o} panoramic sweep, the prism must rotate only 90^{o}, four pictures per prism rotation are necessary in order to maintain a full duty cycle. With one lens and one prism, this condition becomes physically impossible. This therefore leads to either of two possibilities; one lens with two prisms 90^{o} out of phase with each other, or two lenses with one prism.

A version of the first alternative is shown in Figure 1. In this scheme the full duty cycle is essentially satisfied, since there can be continuous film transport with scans made alternately through prisms P1 and P2. To a large measure, the design satisfied the objectives. The feature which discourages its use is primarily the weight of the two prisms. They are necessarily large in size since they have to be located at a considerable distance from the entrance pupil of the lens and are, because of their size, very difficult to make, considering the quality required.

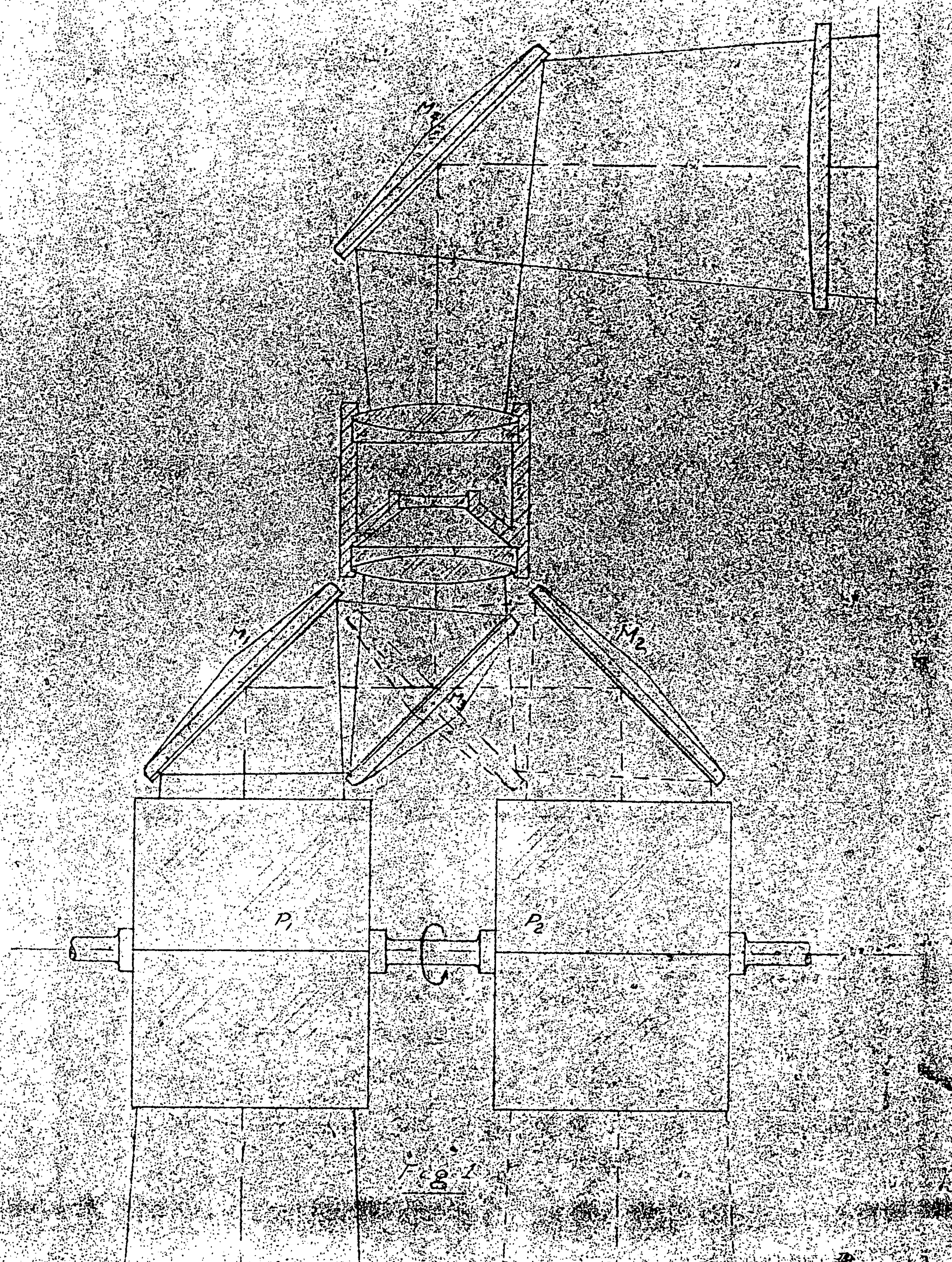


Fig 1

The two prisms in this case would use up about two thirds of the weight allowance for the entire system. Another feature which can be more easily accommodated than the heavy prisms, but which is nevertheless undesirable in an ideal system, is the mirror M3 which is used to switch from one incoming beam to the other. The movement of this mirror is intermittent and thus becomes a source of vibration and transient shock. A notable advantage is the possibility for provision of I. M. C. by means of harmonic oscillation of mirrors M_1 and M_2 in appropriate phase with the prisms.

The basic approach of two scanning members can be taken one step further. Its primary objection, weight, can be reduced by the use of scanning mirrors instead of prisms, as shown in Figure 2. However, a scanning mirror will produce image rotation with respect to the line of scan. To eliminate this objection, a derotation prism, in this case a double-dove prism, must be incorporated, as shown in the figure. This prism is of more reasonable size, being placed close to the lens. Here again is a workable system which, with some exceptions, obeys the previously discussed design features. An added complication is the necessary coordination of the rotation of the prism with that of the scanning mirrors and film. However, the largest problem lies in the ability to rotate the two scanning mirrors M_1 and M_2 accurately enough, since the location of the switching mirror M_3 between them precludes the use of a common shaft. The transient shock effect from the switching mirror remains a problem, as in the first system.

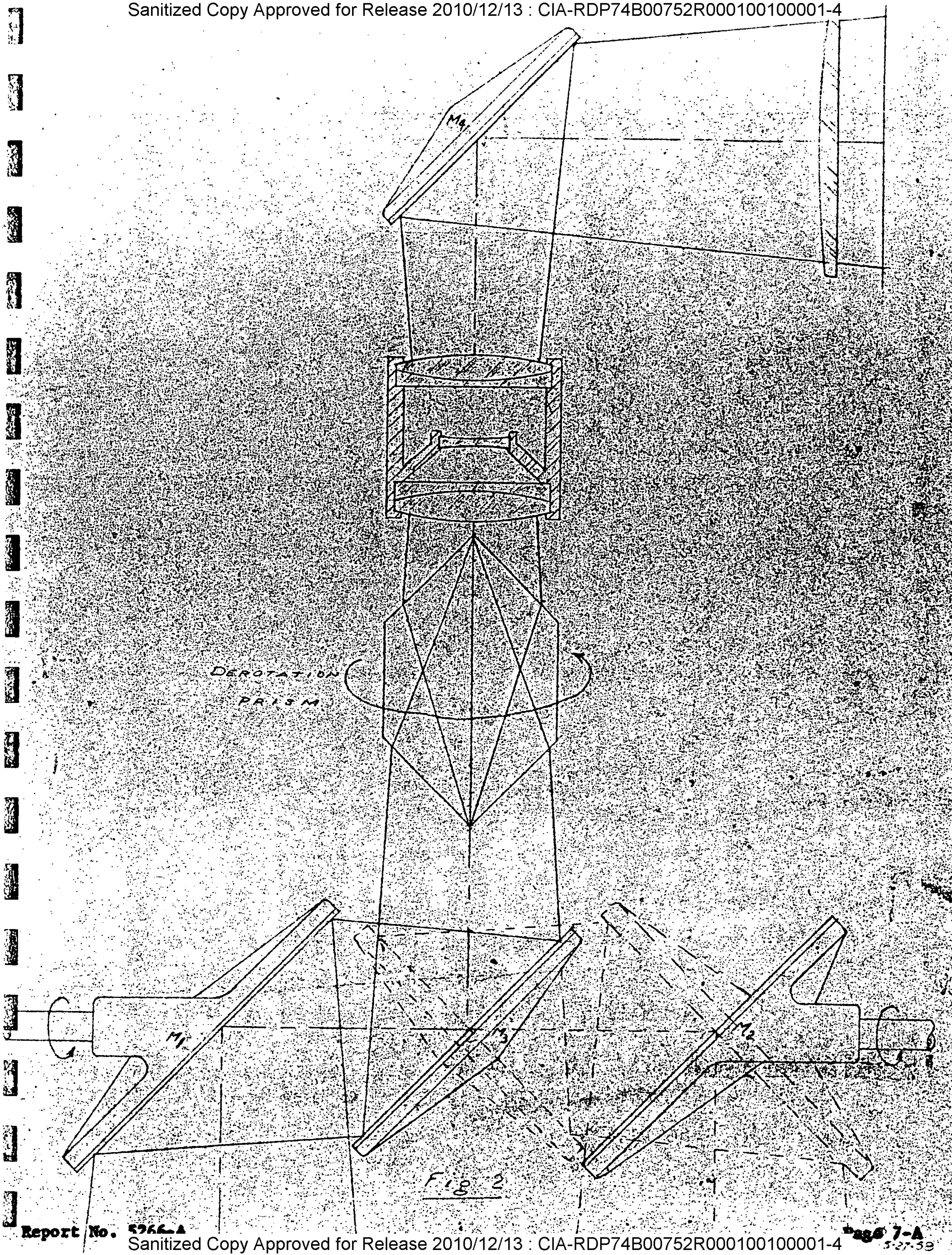


Fig. 2

In considering what changes would have to be incorporated in order to make either or both of the above acceptable, and in reviewing each objection, it becomes obvious under what conditions these approaches become suitable. The primary objection, especially with respect to system 1, is weight and size. This could be reduced considerably by playing the game of give and take with the specifications. Reduction of film format from 9 inches to about 5 inches would decrease the field of view and, consequently, prism size. Another alternative would be to decrease the focal length of the lens to perhaps 12 inches instead of 24 inches. Since weight decreases as the cube of linear decrease of prism size, the weight of the pair of prisms in the 12-inch focal length case would be well within tolerable limits, and the system would be a very feasible one.

The net effect of the evaluation of these two systems, based on two scanning elements and one lens (Figures 1 and 2), indicates that they, as shown, are not of sufficient merit for the design solution if their shortcomings can be overcome with a different approach.

The remaining case to consider is with the use of one prism and two lenses. However, prior to that discussion it would be well to first evaluate the case which departs from the full duty cycle (continuous moving film) condition. There are in this approach several design variations, all characterized by a tempting <u>simplicity</u>. See Figure 3. This is the approach which

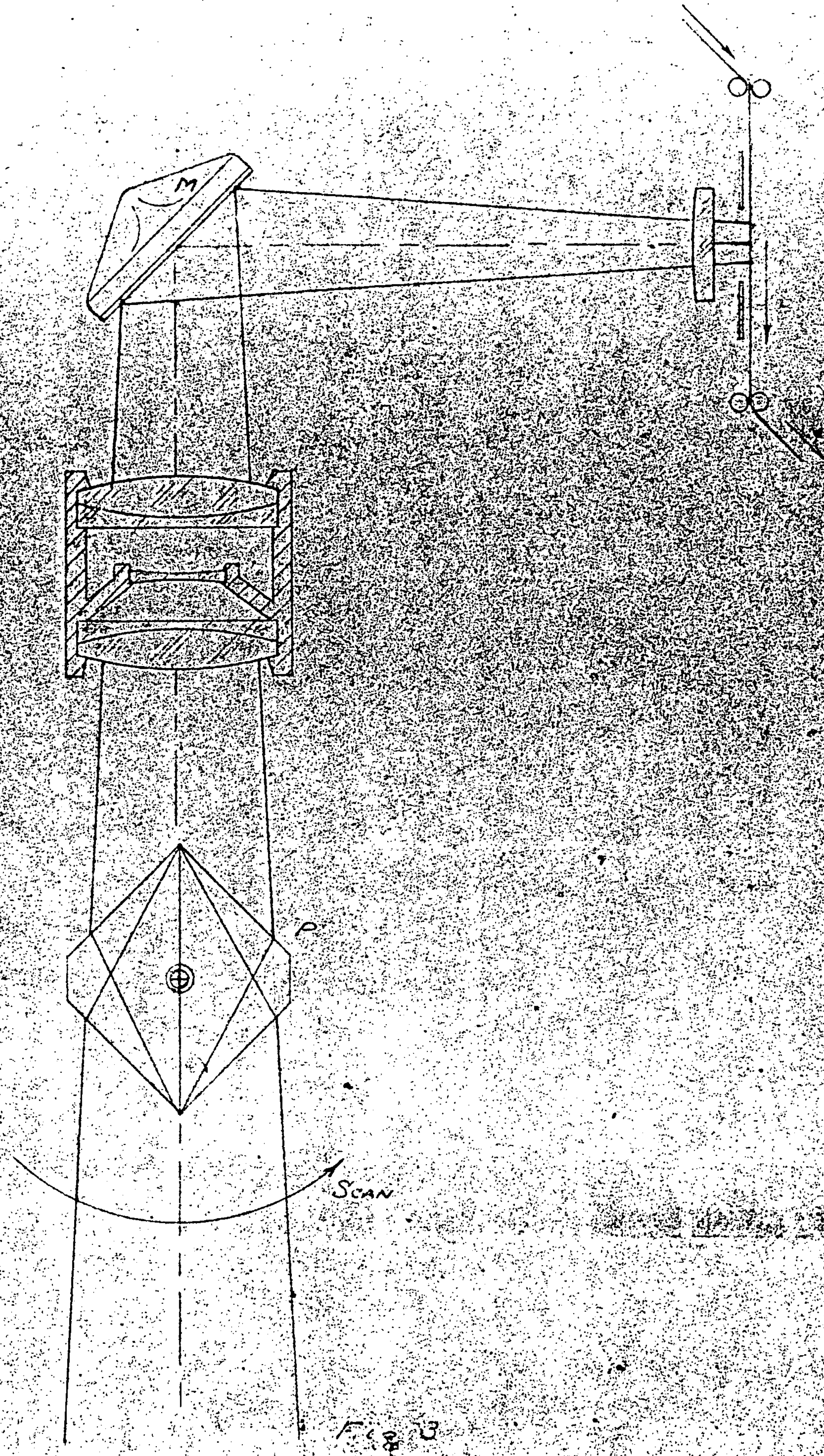


Fig 3

has been followed for the most part until now for most conventional panoramic cameras. The original E-1 panoramic camera and the Perkin-Elmer Model 501 Trackers were both based on this system. It employs essentially a rotating scanning prism coupled with an intermittent film drive. The maximum scanning duty cycle in such a system is necessarily limited to 50%. This would require faster scan rates to meet the desired specifications. It would also necessitate the acceleration of film from a stopped position to a high, yet constant velocity. The specification which most seriously limits us in this case is the rapid sequence required of 1 scan per second (which we have considered important). It is doubtful that vibrational transients affecting the internal optical parts and the external stabilization could be damped out in less than several seconds after the film is started.

These objections, in the light of current specifications, are such as to eliminate this type of a system from further consideration.

The Choice

The previously mentioned case of one prism and two lenses remains as a possible solution. A configuration is shown in Figure 4. It becomes immediately apparent that the weight problem of the prism is no longer a factor. Since the lenses are close to the prism, the prism can be smaller and, in addition, there is only one prism instead of the two used in system 1. Here too there

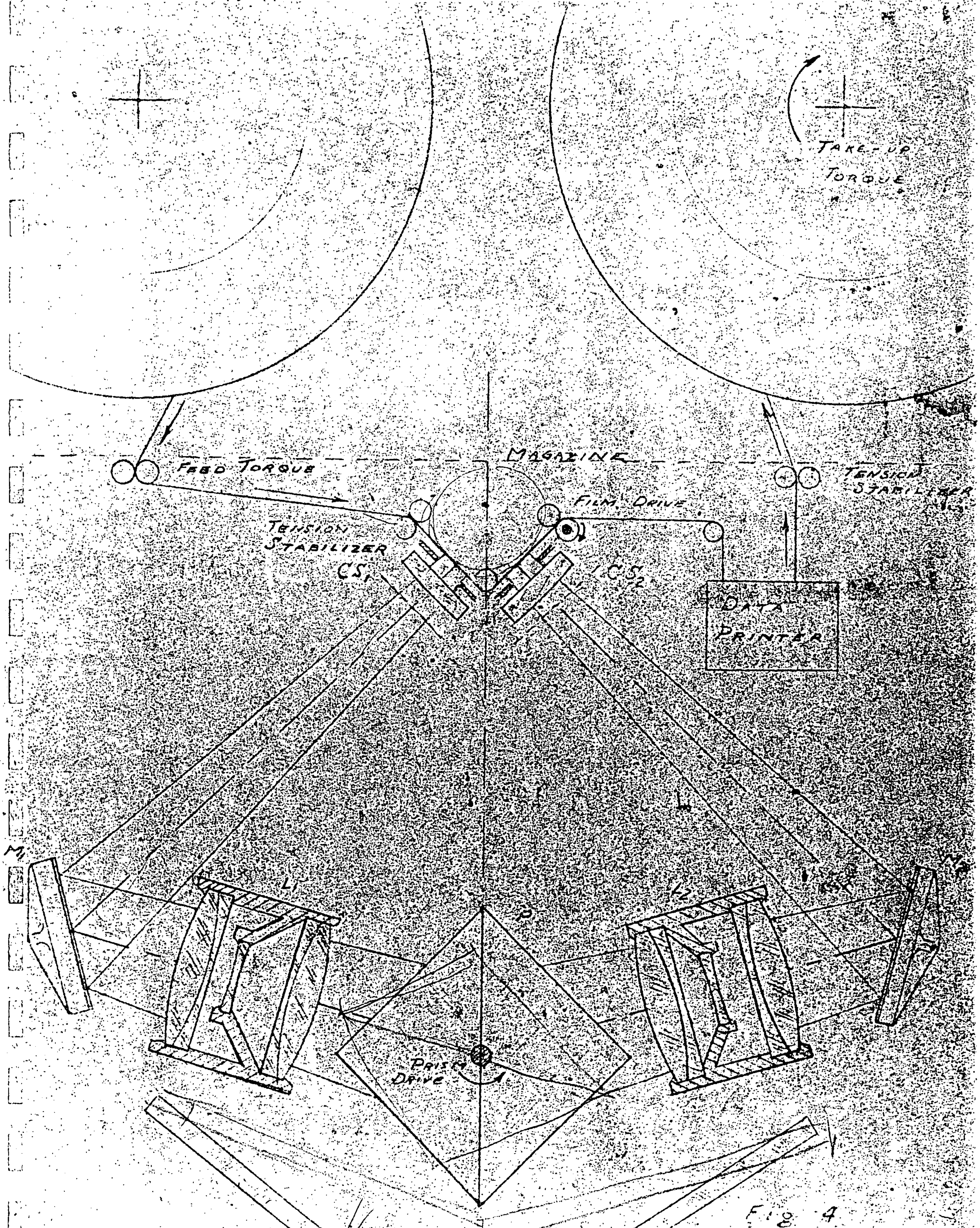

TAKE-UP
TORQUE
MAGAZINE
FEED TORQUE
TENSION
STABILIZER
FILM DRIVE
TENSION
STABILIZER
CS_1
CS_2
DATA
PRINTER
M_1
L_1
L_2
M_2
P
PRISM
DRIVE

Fig. 4

is a minimum number of reflecting elements, only the one mirror being used in each optical system as normally required for image erection. There is no flip-flop mirror to induce shock, and all functions are continuous. The system truly seems to adhere to every aspect of the design approach objectives.

Some specific features in detail are worth noting in considering the system of Figure 4.

1. The lenses are placed at such angular positions that an active scan from each in turn is accomplished without overlapping of duty cycles. The prism of Figure 4 is shown at the transition point between the start of scan for lens L1, and the end of scan for lens L2. The chosen positions furthermore are such that a 150 degree transverse field of view is scanned by each lens combined with the prism.

2. The images from the two halves of the optical systems are alternately brought to the film through two focal-plane slits, with displacement such that the film passes them sequentially. Lightweight capping shutters CS1 and CS2 open alternately (in time with the prism) during the active scan exposures. In this fashion, the dual beams are recombined directly on the film without multiple mirrors or heavy oscillating parts.

3. The deployment of the 2 slits along the film path serves to compensate for the unsymmetrical angular placement of the lenses so that the spaces between frames are equalized on the film.

4. The divergent optical paths provide an opportunity for a light-weight suspension system for stabilization in the unoccupied central region. A naturally symmetrical system is a further advantage.

5. Dual usage of the prism is obtained, with many consequent advantages, including nearly 100% duty cycle, film speed during scan reduced to 1/2, and smooth continuous motion of all moving parts. The best conditions are thus provided for meeting the requirements of synchronization. Furthermore, the efficient duty-cycle figure is in line with the strong desire for a system capable of recording maximum information per pound.

There are two unique problems with this system, both having solutions. One is a limitation of the angle of scan, due to blocking of the prism line-of-sight by the lens mounts. This blocking occurs only in the neighborhood of the limits of the required 150 degree scan, and may amount to one f-stop if not corrected. Since the interference occurs with an unused portion of the front lens element it is entirely feasible to remove a portion of the disc if necessary. Exposure variation caused by residual blocking can be compensated by control of slit width during scan.

The other limitation is in regard to the stereo overlap in the flight direction. The scan cycling is such as to record two pictures in succession with a short lapse before the next pair of exposures. This condition is inherent because of the need to place the lenses at somewhat less than 180 degrees apart. The image overlap can be corrected simply by a small fixed displacement of the lens axes relative to the center of the format. (See Optical System Details)

The arrangement as shown in Figure 4, with lenses arranged

150 degrees apart, is considered the best balance between the usage problems of coverage and overlap.

We consider this two-lens continuous-duty concept to be a significant advancement, providing a unique combination of functions which are basically simple, therefore predictable.

The foremost problem of dynamic optical scanning; the use of intermittent mechanisms is completely eliminated.

OPTICAL SYSTEM DETAILS

Some interesting effects result from the optical geometry of the proposed system. Figure (5) is a development of the optical system showing the two lenses, the optical axes of each making an angle θ with the horizontal, and the two positions of the mirror surface of the rotating prism at which the nadir falls on the optical axes of the lenses. These positions are marked (1) and (2). The mirror rotates with a constant angular velocity $\dot{\phi}$ in rad/sec.

Spacing of Successive Film Frames

The angular displacement of the prism between successive exposures is then $\frac{\pi}{2} \pm \theta$ radians, and since the image scan angle is twice the prism scan angle, the angular displacement referred to the film is $\pi \pm 2\theta$ radians. The intervals between frames would therefore differ by 4θ for a single slit system. By using two slits and making the path difference on the film equivalent to half this value (2θ) the frame intervals on film may be equalized. The required distance is $2\theta F$ where F is the focal length of the lens. In the design under consideration, $\theta = \frac{\pi}{12}$ and $F = 24$ inches. (Fig. 6) yielding a separation of 12.57 inches.

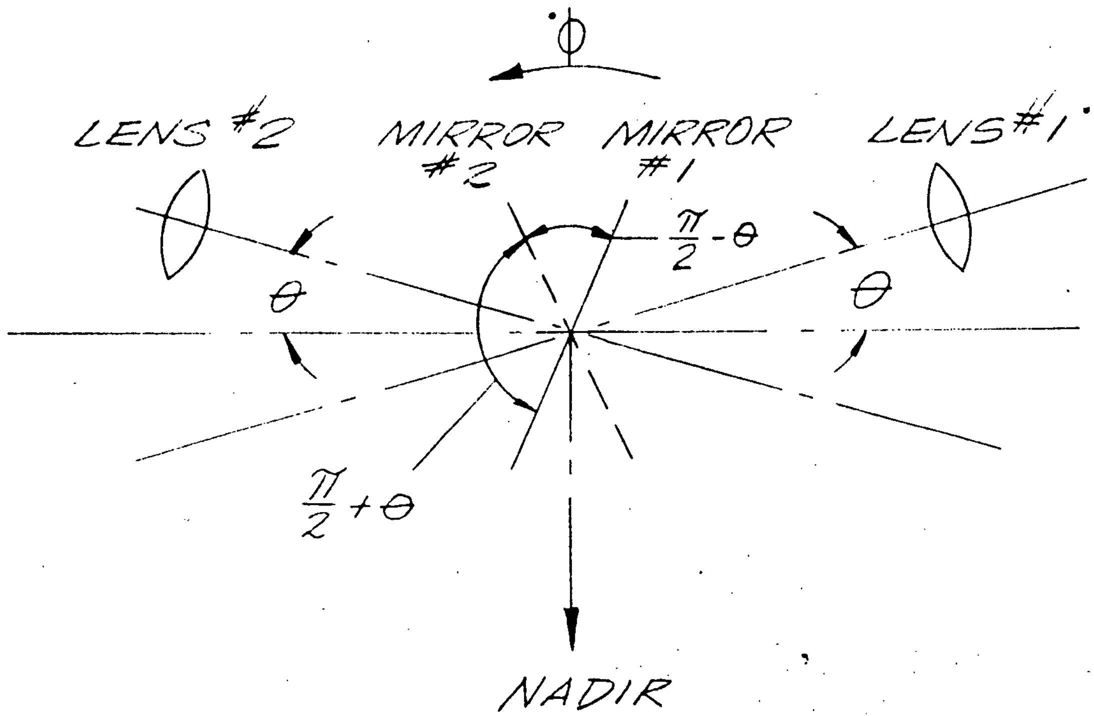

ϕ
LENS #2
MIRROR #2
MIRROR #1
LENS #1
$\frac{\pi}{2}-\theta$
θ
θ
$\frac{\pi}{2}+\theta$
NADIR

FIG-5

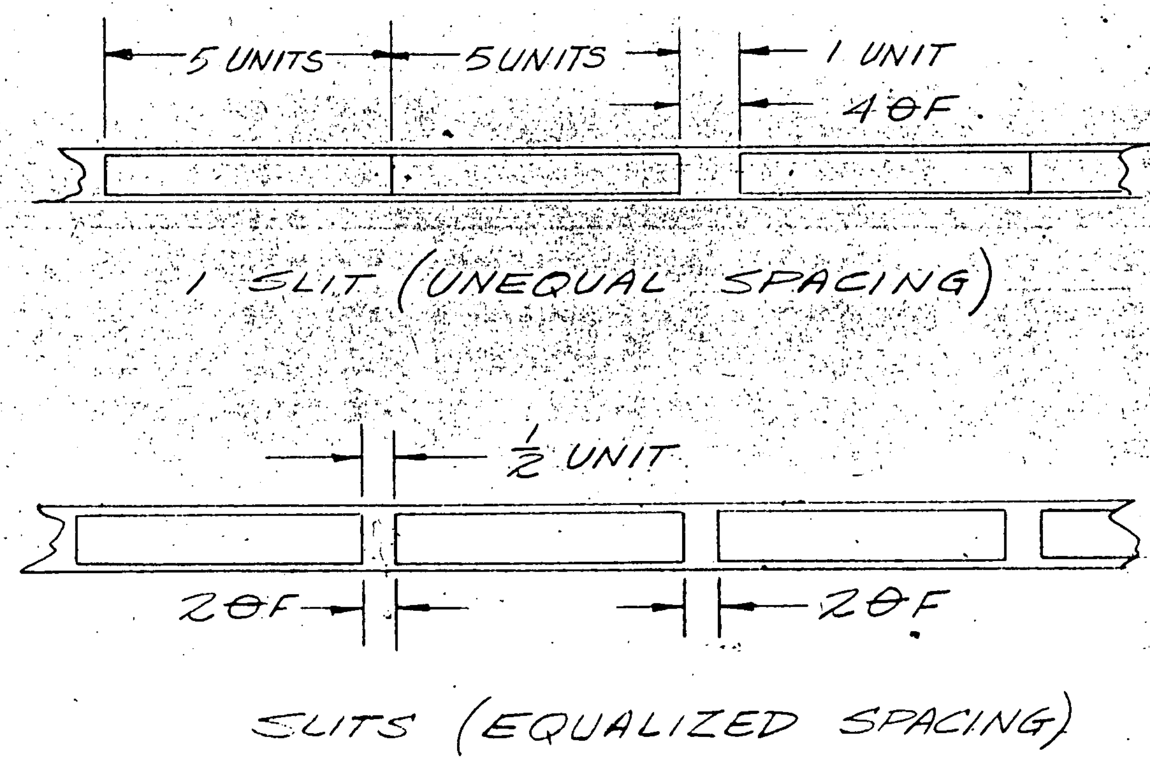

5 UNITS
5 UNITS
1 UNIT
$4\theta F$
1 SLIT (UNEQUAL SPACING)
$\frac{1}{2}$ UNIT
$2\theta F$
$2\theta F$
SLITS (EQUALIZED SPACING)

FIG-6

The Time Interval Between Frames

The time interval between successive frames is

$$\Delta t = \frac{\pi/2 \pm \theta}{\dot\phi}$$

In this design Δt is therefore $\frac{\pi}{12}\frac{(6 \pm 1)}{\dot\phi}$ and the time intervals between frames (and therefore the stereo angles) alternate in ratio of 5 to 7.

Since any solution which does not lead to constant film speed and prism rotation is undesirable, the alternatives are to reduce θ to the lowest possible value or to make θ appear smaller by an optical expedient. We have calculated that the vignetting problem will lead to a value of θ of the order of $\frac{\pi}{12}$. Optically θ could be made to appear smaller by using the lens off axis by an angle equal to θ. This device would impose extremely difficult conditions on lens design and would raise the prism, thus increasing the vignetting problem at the limits of the angle of scan.

We believe that the best solution lies in using the smallest possible value of θ consistent with the vignetting consideration and in accepting the resulting alternation of the stereo angle.

The Overlap on Film Frames

Since the stereo base or time interval between successive frames alternates in the ratio of 5 to 7, it follows, if each lens is centered on the film center line, that the film overlap will vary alternately in the same ratio. By parallel displacement of the lenses along the flight axis, so that the first lens looks slightly backward and the second slightly forward, the overlap on the film can be made constant. (See Figure 7). For a 55% overlap, the image would be displaced 45% of the film width for each scan, or 90% for the full cycle interval of two scans. Since the time intervals are in the ratio of 5 to 7, the actual image displacements on film, in the case before lens displacement, alternate between 37-1/2% and 52-1/2% of film width. Separation of the lenses by half the difference (7-1/2%) results in equal displacements of 45%, or the desired overlap of 55%. The displacement of 7-1/2% of film width of 9 inches amounts to .675 inches. To accommodate the lens offset, the prism is increased in length by the same amount. The field requirement of the lens is also increased. The stereo angle is not affected by these adjustments and alternates between 11° 20' and 8° 4'.

Prism Speed

In our proposed design, the prism speed $\dot{\phi}$ is proportional to V/H.

$$\dot{\phi} = K \frac{V}{H}$$

The constant K is determined by the desired overlap ratio. For a two scan cycle of time T the prism will

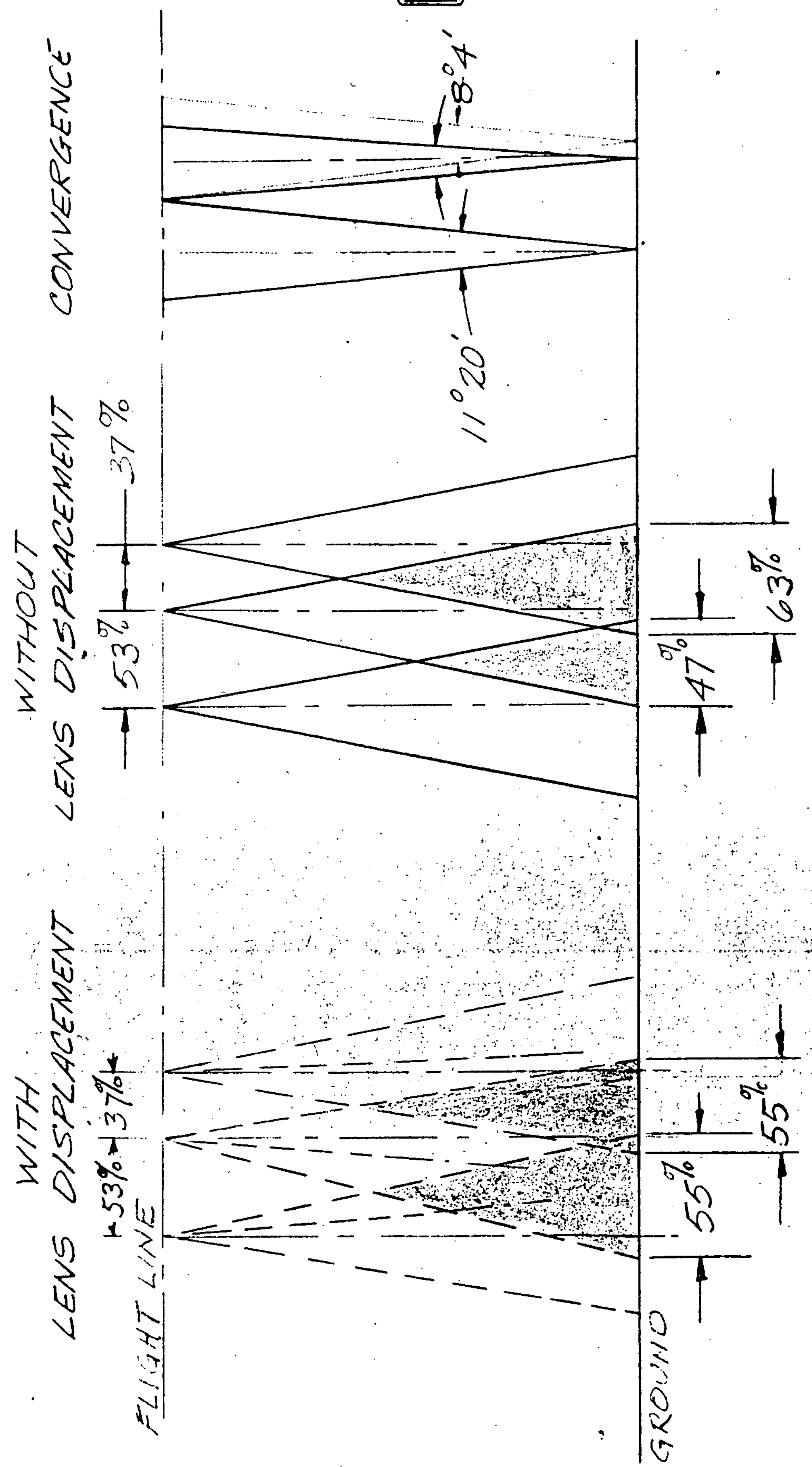


FIG-7: OVERLAP

have rotated π radians while for a 55% overlap the picture will have been displaced by 90% of the picture width.(W). Thus,

$$\frac{.90\,W}{F} = \frac{VT}{H} = \frac{V\,\pi}{H\,\dot{\phi}} = \frac{\pi}{K}$$

Therefore,

$$K = \frac{\pi F}{.9\,w} = 2.96\,\pi$$

and prism speed

$$\dot{\phi} = 2.96\,\pi\,\frac{V}{H} \quad \text{radians/sec.}$$

Image Motion Compensation

An examination of the geometry of the scan method shows that the image motion is accurately sinusoidal with the maximum velocity occurring at the nadir. According to the relation

$\delta = \delta_o \sin \omega t$ where $\omega = 2\dot{\phi}$ since the scanning angular velocity is twice the angular velocity of the prism and where δ is the instantaneous displacement of the image and δ_o is the amplitude of motion. Differentiating,

$$\frac{d\delta}{dt} = 2\dot{\phi}\,\delta_o \cos 2\dot{\phi} t \quad \text{and} \quad \left(\frac{d\delta}{dt}\right)_{max} = 2\dot{\phi}\,\delta_o$$

Since the image velocity at the nadir is also represented by $\frac{V}{H}F$, the two expressions may be equated

$$2\dot{\phi}\,\delta_o = \frac{V}{H}F$$

$$\delta_o = \frac{VF}{2\dot{\phi}H} = \frac{F}{2K} = 1.29 \text{ inches}$$

The peak to peak amplitude will then be 2.58 inches.

The Lens Field

The diameter of the lens field equals the length of slit (9"), plus the lens offset distance (.675") plus the peak movement for IMC (2.58") for a total of 12.26 inches. The lens must be designed therefore for a half field angle of 14°-20'.

Area-Weighting

The manner in which the film and lens field move with respect to each other results in the lens field coverage per frame illustrated in Figure 8. This distribution results in a considerably different area-weighting function for AWAR determination than that applied to a stationary field-to-frame relation. In fact the variation in resolving power which would result in a constant area-weighted resolution across the entire field would have the same shape as the field coverage curve. The shape of the curve corresponds in general to the natural manner in which the resolution falls off in a normal lens field, resulting in a considerably more efficient use of the high information-gathering capacity of the center of the field than is obtained in the usual static frame. The reason for this is that the strip camera covers a much larger portion of the frame area with the naturally high quality center of the lens field than the static-frame camera.

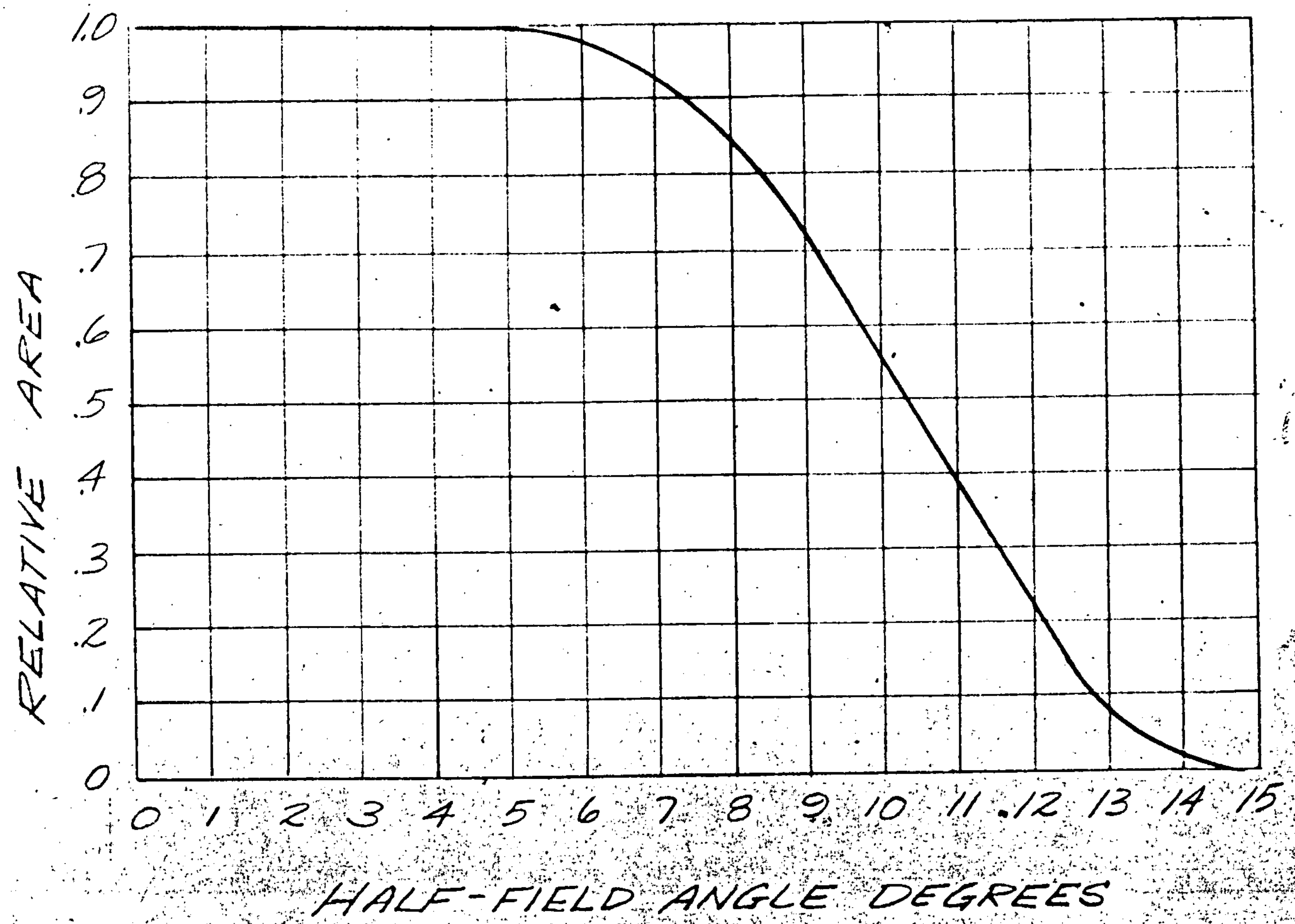


FIG - 8 LENS FIELD COVERAGE PER FRAME

Optical Limitations on Image Quality

Limiting resolution is a good measure of the information content density (bits of information per unit length) stored by the lens-film combination. However, it depends on the minimum signal discriminable above the noise (graininess) of the film, and therefore on the contrast of detail in the image. This image contrast depends on the apparent contrast of the object and on the contrast degradation of the lens-film combination. The object contrast is generally independent of detail size, but the lens-film combination will degrade the contrast in the image, the degradation increasing as the detail size decreases.

Figure 9 illustrates how the relative performance of two different photographic systems can depend on the contrast of the object being photographed. Assuming that the image contrast threshold is independent of detail size, the horizontal dashed lines indicate three thresholds relative to the lens-film degradation characteristic, T_1 being for relatively high object contrast, T_2 for half the contrast for T_1, and T_3 for half the contrast for T_2. At high object contrast system A is superior to system B, at intermediate object contrast both will record the same amount of information although B will give a sharper image, and at low object contrast system B is superior.

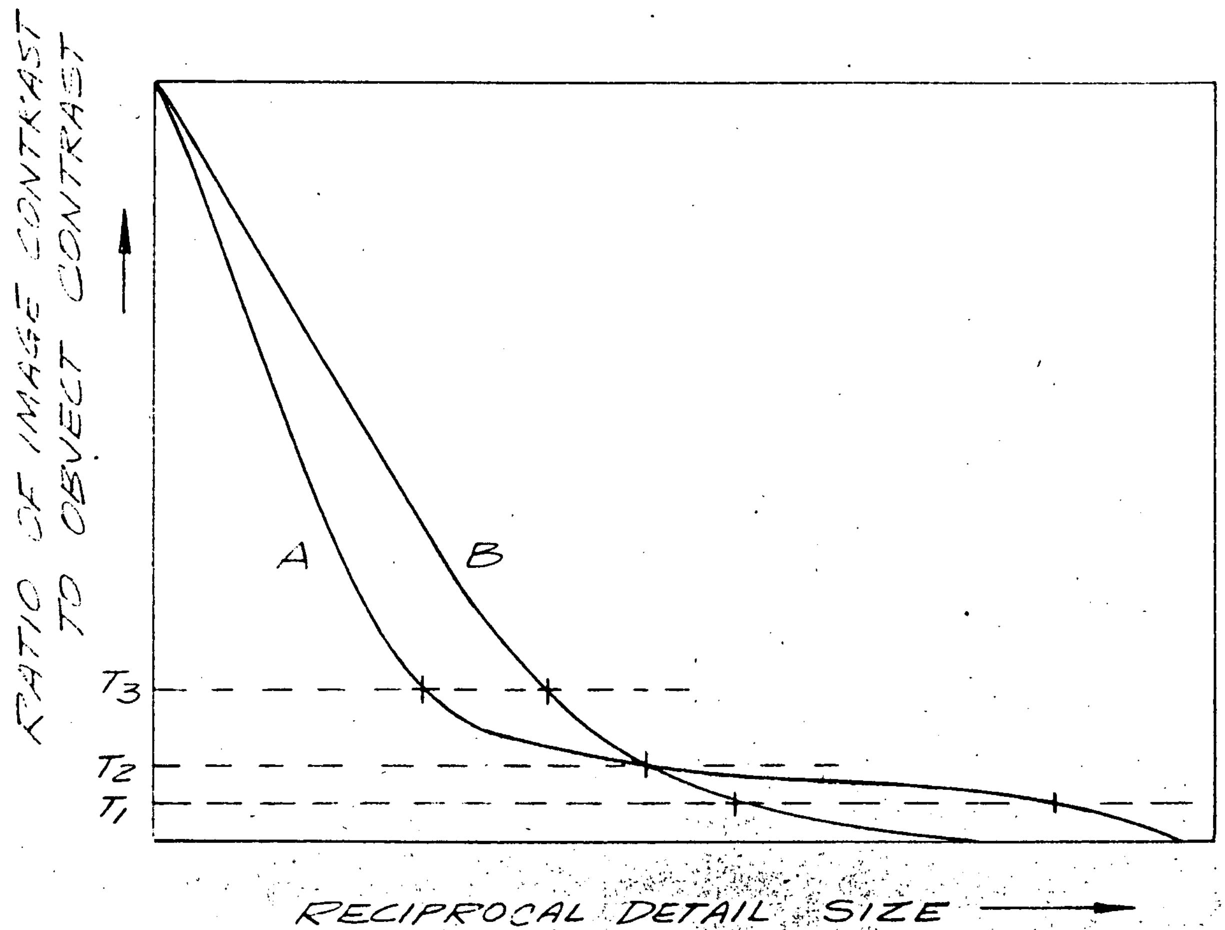
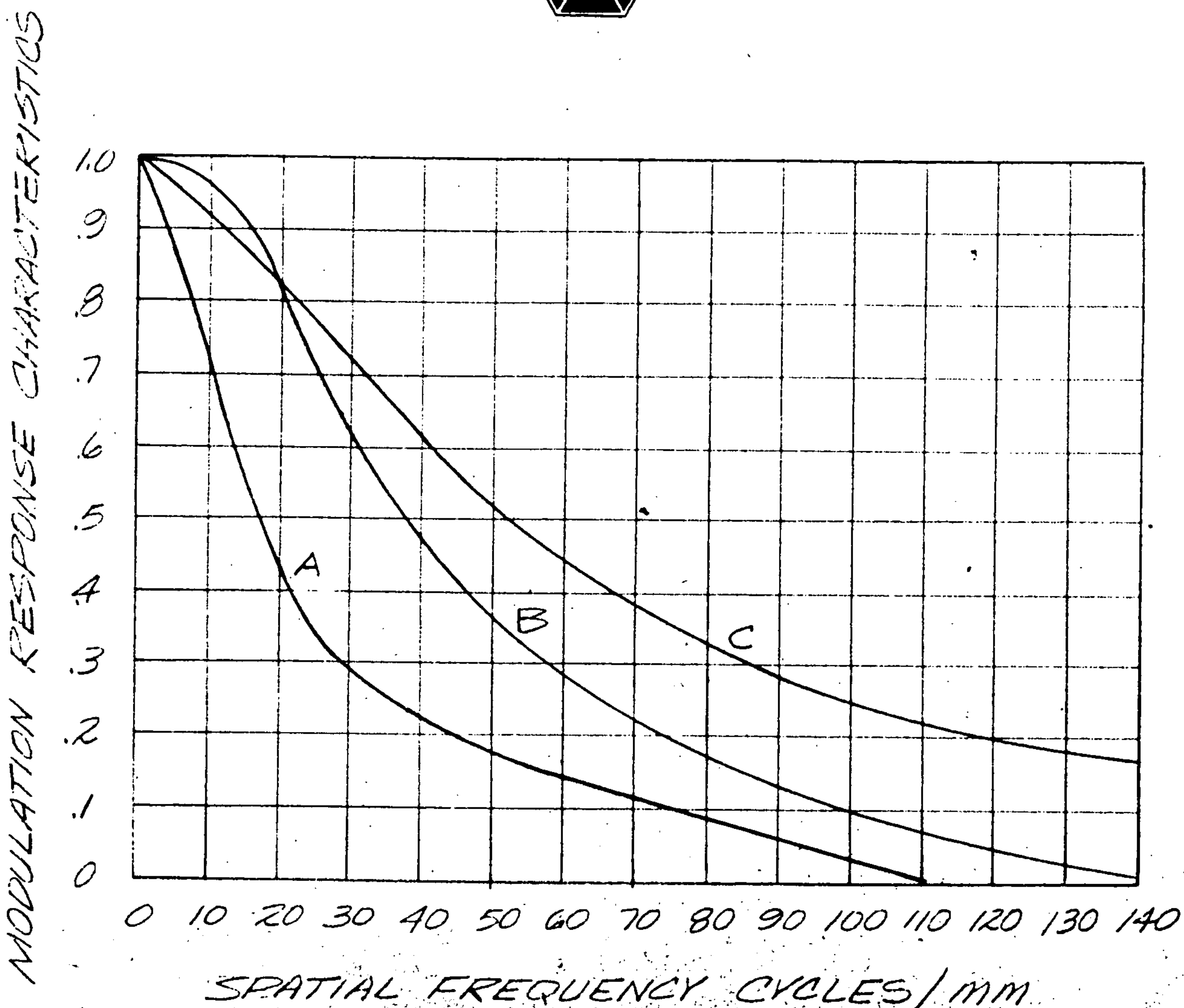


FIG-9 DEPENDENCE OF RESOLUTION LIMIT ON OBJECT CONTRAST

The choice between the two systems will depend on the contrast conditions of the objects to be photographed. If the preponderance of objects will have medium to high contrast, system A will be the better information-gatherer. If the preponderance of objects will have medium to low contrast, over a period of time system B will gather more information than system A.

The most effective technique for analyzing the contrast-degrading properties of a photographic system is one in which the object element is a spatial sinusoidal pattern. Any object can be decomposed into sinusoidal elements by the application of Fourier analysis, and the contrast degradation can be reinterpreted as the reduction in the amplitude of the sinusoidal element as a function of its spatial frequency. A major advantage of this technique is that the optical system and the film can be evaluated independently and the performance of the two predicted by simply multiplying their characteristics together. Figure 10 shows the modulation response characteristics for three samples of different types of film.

The modulation transfer characteristic of the optical system is limited principally by three factors. These are diffraction, secondary color, and aberration.



	FILM TYPE	DEVELOPER	DEVELOPMENT TIME
A	TRI-X AERECON	D-19	8' 30"
B	PLUS-X AERECON	D-19	6'
C	1182	D-19	8'

FIG-10 MODULATION RESPONSE CHARACTERISTICS OF PARTICULAR SAMPLES OF THREE EMULSION TYPES

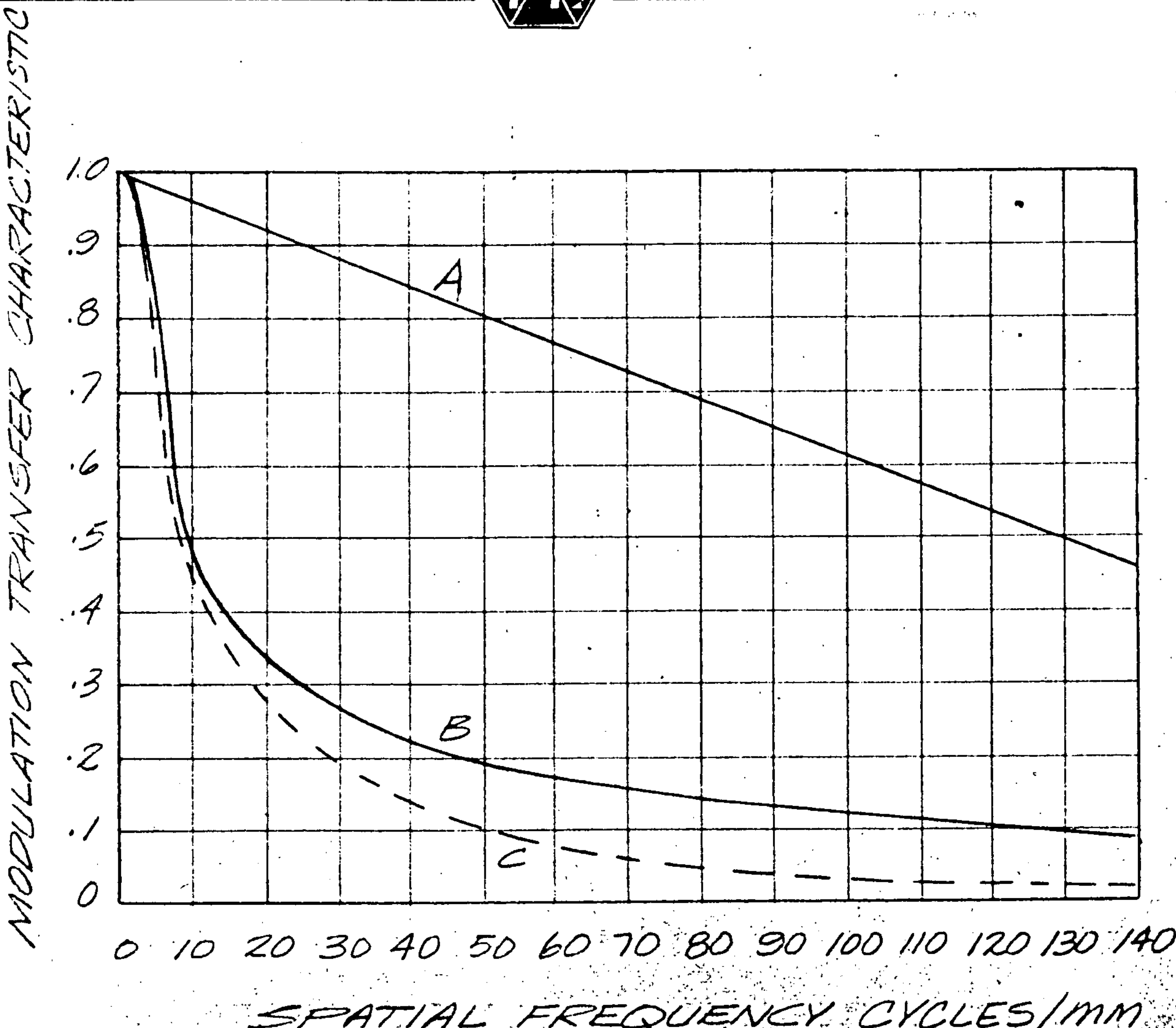
The degradation due to diffraction is determined solely by the relative aperture of the system and cannot be improved.

Secondary color is under very limited control. Any attempt to reduce it by an appreciable amount will increase the weight of the optical system and make the correction of off-axis aberrations more difficult.

The combined effect of diffraction and secondary color will result in a degradation which can only be made worse by the introduction of aberrations. Thus a calculation of the modulation transfer characteristic of a system limited by diffraction and secondary color, but without aberration, will give an upper limit which can be approached but not exceeded in the design of the system.

Figure 11 shows this curve as well as one for a system limited by diffraction in the absence of secondary color. It also shows the overall system characteristic with type 1182 film when the aberrations of the optical system are perfectly corrected.

The amount of secondary color is for a 24-inch focal length anastigmat. No refracting system known to us having the required f/no., focal length, and field has appreciably less secondary color.

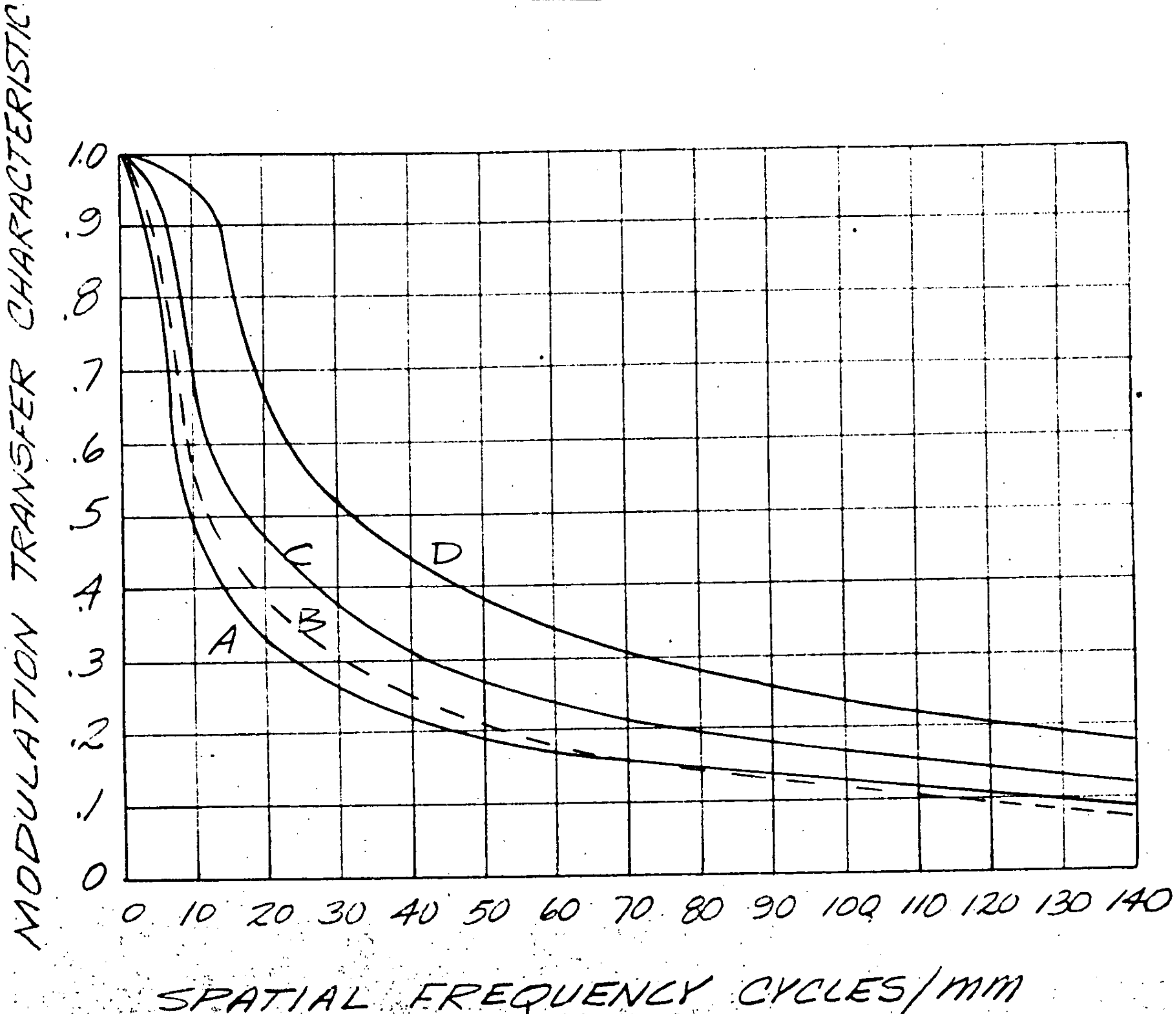


	f NUMBER	SECONDARY COLOR	SPECTRAL BANDWIDTH
A	5.6	.000"	170 mμ
B	5.6	.020"	170 mμ
C	CURVE B + EMULSION TYPE 1182		

FIG-11 EFFECT OF DIFFRACTION AND SECONDARY COLOR ON MODULATION TRANSFER CHARACTERISTICS

It is apparent that the degradation resulting from secondary color leaves very little margin for the designer to work within. An attempt to maximize the curve in the vicinity of 100 cycles/mm could result in a flattening of the curve at the intermediate frequencies producing a system like A in Figure 9. If the objects to be photographed are generally of low contrast, it would be better to maximize the intermediate region even though this might result in a high contrast resolution limit at less than 100 cycles/mm.

The seriousness of the degradation resulting from secondary color has prompted us to investigate its improvement. Figure 12 shows the improvement obtained by stopping the lens down, by reducing the secondary color, or by reducing the spectral bandwidth. Stopping the lens down might be expected to improve the image by increasing the depth of focus, but this gain is largely offset by the increased diffraction. Reducing the secondary color by a factor of two results in a modest gain, but this might well be offset by the difficulty in keeping down the aberrations off-axis. Reducing the spectral bandwidth by a factor of two results in an appreciable gain at the cost of a doubling of either the effective exposure time or the film sensitivity.



	f/NUMBER	SECONDARY COLOR	SPECTRAL BANDWIDTH
A	5.6	.020"	170 mu
B	8 *	.020"	170 mu
C	5.6	.010" *	170 mu
D	5.6	.020"	85 mu *

* CHANGE FROM NOMINAL

FIG - 12 IMPROVEMENT OF MODULATION TRANSFER CHARACTERISTIC IN THE PRESENCE OF SECONDARY COLOR

Lens

We have in our possession a design which comes close to the specifications required for this system. As it stands now it is a 24" f/8 5-element lens designed by Dr. James G. Baker for a 9" x 18" format having a curved field. For a limited spectral region this lens can be made diffraction limited. (Figure 13).

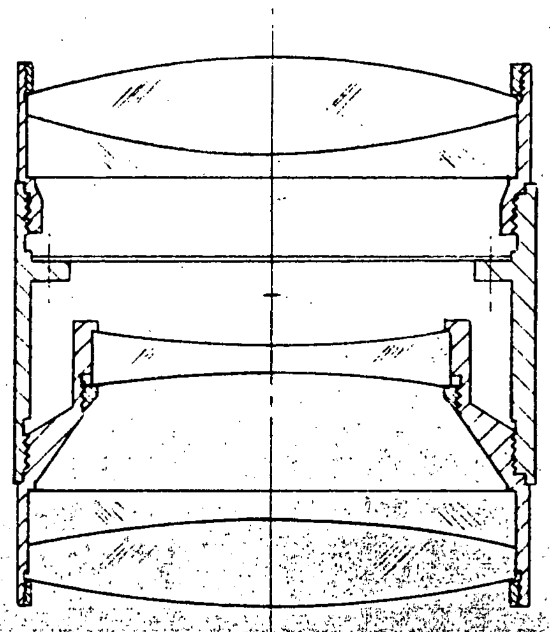
The only major design modifications required for this particular application are an aspheric field flattener close to the image surface, and possibly aspheric figuring within the lens to maintain high image quality at the larger f/5.6 stop.

We intend, during the design study period, to investigate the possibility of reducing the secondary color in the above described lens, leading toward an apochromatic version. The outcome cannot be predicted with certainty.

We believe that the above approach to the problem has a better chance for success than any other approach.

This statement is made, recognizing that practical weight and size restrictions rule out Schmidt type systems, and that no deviation should be permitted in the field coverage and aperture requirements.

While this matter has been given considerable study during the course of this proposal, we intend to do much more work in surveying the total optical industry for other optical designs that might be suitable for the requirement. Among other lens systems that have been brought to our attention are the Pacific Optical 24" f-6 and the 24" high acuity lens designed by Dr. Baker. We will closely coordinate all of our findings in this survey with the government contracting officer.



f/5.6

FIGURE 13

HALF SIZE

Prism

The prism dimensions for the f/5.6 camera are as follows: The square transverse cross-section of the assembly is 6.9 x 6.9 inches. The length along the axis of rotation is 10.8 inches. These dimensions are for LF-2 glass. The weight is 59 lbs. A pair of full right prisms is required, that is, no truncation is allowable, because the application calls for deviation angles which reach from 0 degrees to 150 degrees and the full available aperture of the right prism is needed. The mounting method will use the most advanced bonding technique to fasten metal bosses to the prism ends. The two halves will be held together by bolting trunnions to the bosses. The trunnions will be supported in bearings for rotation and coupling to the drive system.

Slit Considerations

In a high resolution system of this type, slit width becomes limited by an effect normally ignored since this effect is usually of negligible order. This effect is an apparent change in magnification for off axis positions.

Referring to Figure 14 consider a point (A) in the center of the slit at a distance Ro from the optical axis (o) of the lens. The ray to the point makes an angle θ with the optical axis. The two points A and O correspond to two points on the ground which subtend the constant angle θ.

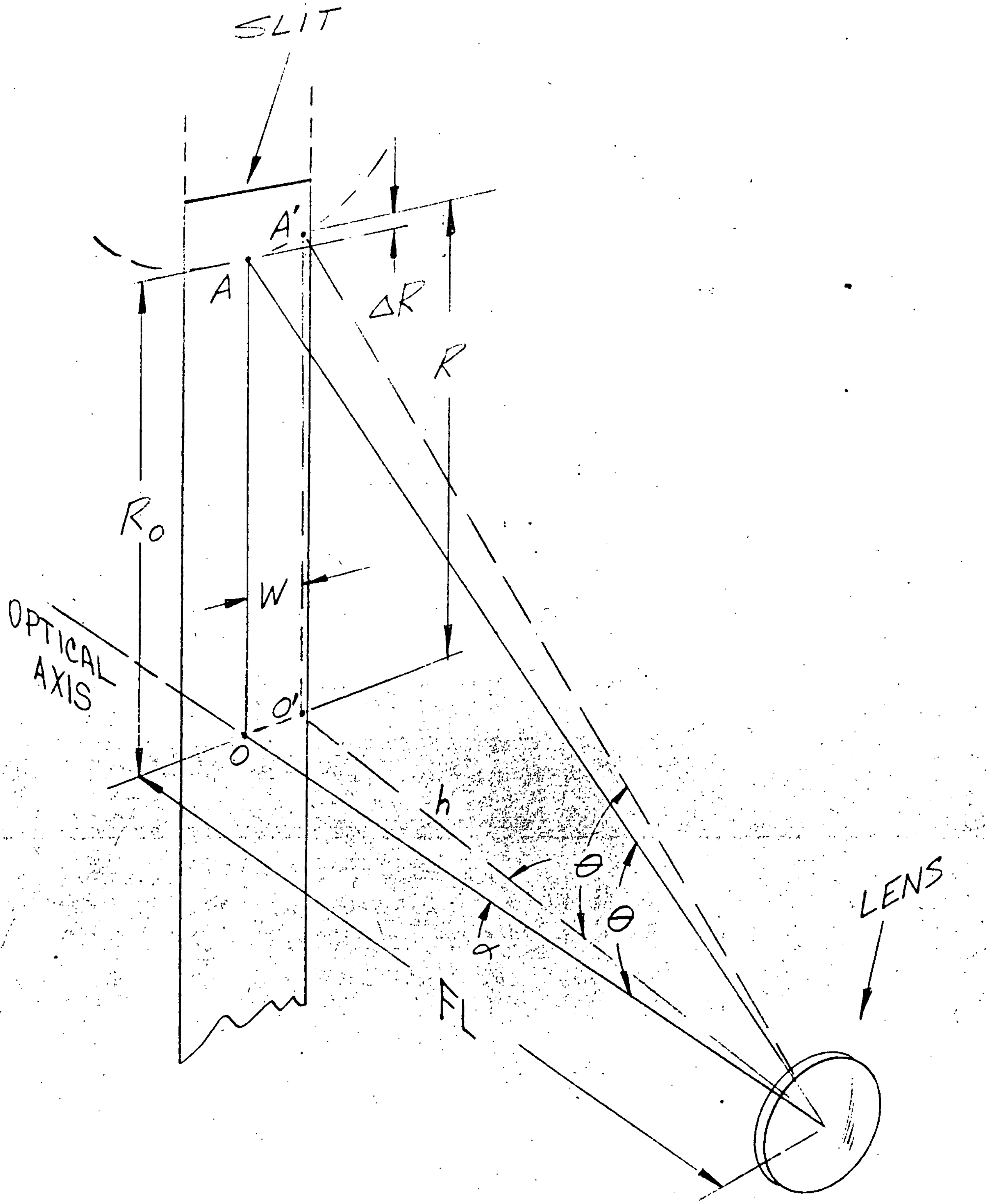


FIG-14 IMAGE GEOMETRY AT SLIT

from the lens during the time of scan. A short time later, after scanning through an angle α, the image points are moved to different positions on the film denoted by A' and O' still subtending an angle θ from the lens. The distance $A'O' = R = h \tan\theta = h \frac{Ro}{F}$.

where h is the slant distance from lens to O'

and F is the focal length of the lens

The image point of O has moved a distance w on the film. From the geometry $F = h \cos\alpha$

$$\text{Thus } R = h\frac{Ro}{F} = \frac{Ro}{F}\frac{F}{\cos\alpha} = \frac{Ro}{\cos\alpha} = R \sec\alpha$$

The radial shift of the point ΔR is $R - Ro = Ro\ (\sec\alpha - 1)$ which may be approximated for small values by $\Delta R \cong Ro\,\alpha^2$ with α measured in radians. Since $w = h \sin\alpha \cong h\alpha$ the expression becomes $\Delta R \cong \frac{R_o w^2}{h^2} \cong \frac{R_o w^2}{F^2}$

It is evident that the image shift is directly proportional to the distance from the center line of the film and increases approximately as a square law function with the slit width.

For an AWAR requirement of 100 l/mm, permissible image shift at the edge of the field would be of the order of 0.01/mm or .0004 inch.

For the proposed system the half slit width

$$w \cong \sqrt{\frac{.0004 \times (24)^2}{6.13}} \cong .19$$

The slit width $2W \cong .38$ inches.

Trigonometrically, the permissible slit width is .53 inches.

Since the maximum values of Ro are encountered only at extreme angles of scan where the picture will be repeated several times due to reduced overlap, a larger slit width of the order of 5/8 inch is considered tolerable.

In examining the above development of the equations relating to image shift during scan, it will be seen that the image shift would be entirely eliminated if the slant distance (h) were a constant equal to the focal length (F). This implies the use of a concave cylindrical field of radius F. It is interesting to note that the direction of curvature of this focal plane is opposite to that resulting from the use of a drum, and therefore imposes more serious limitations on the design of a cylindrical field flattener.

To sum up, this effect of image shift effectively establishes the maximum slit width for use with a flat focal plane and points out the requirement for detailed optical investigation into the use of a cylindrical field flattener.

Windows

There are special requirements for the 3-section window (see Figure 4). The material must be lens quality glass, each section approximately 9" x 12" x 1" thick, with edge design integrated with the window mount design. The surface figure must be at least as good as 1/4 wave net for both surfaces, over any 4" circle. Each individual surface should be flat within 1 wave over any 4" circle. In addition, wedge-compensation must be added to the two oblique windows to correct for twinning caused by differential refraction in the air path, due to pressurization. This twinning occurs in uncorrected systems at the section where the aperture is split through adjacent windows.

Detail Features - Mechanical

Image Motion Compensation Mechanism

The IMC method most suitable is the translation of each lens parallel to the flight direction in a sinusoidal fashion. The alternate use of the two lenses eliminates the problem of the necessary quick-return motion which would be required if the entire camera were oscillated in the pitch direction, and releases the stabilization system for pure steadying action. The required motion for exact IMC is purely sinusoidal. Since the entire camera operating speed is controlled in proportion to V/H, the lens displacement can be driven with cam followers located at the correct phase angle, working from a single precision cam on the prism shaft. This cam is required to provide two cycles of harmonic displacement at the lenses, with an amplitude (1/2 peak to peak) of 1.29 inches, per prism turn. Special care must be taken in the design of a kinematic suspension for each lens which permits frictionless linear motion parallel to the flight direction. The lens motions are such as to almost completely counterbalance each other.

The compensation achieved is without geometrical compromises, and has its accuracy assured by built-in component precision. The mechanical motions are smooth and shockless and thus do not impose problems on other functions in the camera system.

Synchronizing Drive

The all-important mechanical coupling between film drive and prism will receive careful attention in development. The image must be displaced across the .625-inch maximum slit width, keeping pace with the moving film, and with a deviation not exceeding .005 mm. (.0002 in.). This amount assumes essentially constant velocity difference, or low-frequency oscillatory velocity error. The percent accuracy required is 2 parts in 6250 or .03% which is a conservative figure permitting resolution of 100 lines/mm at high contrast.

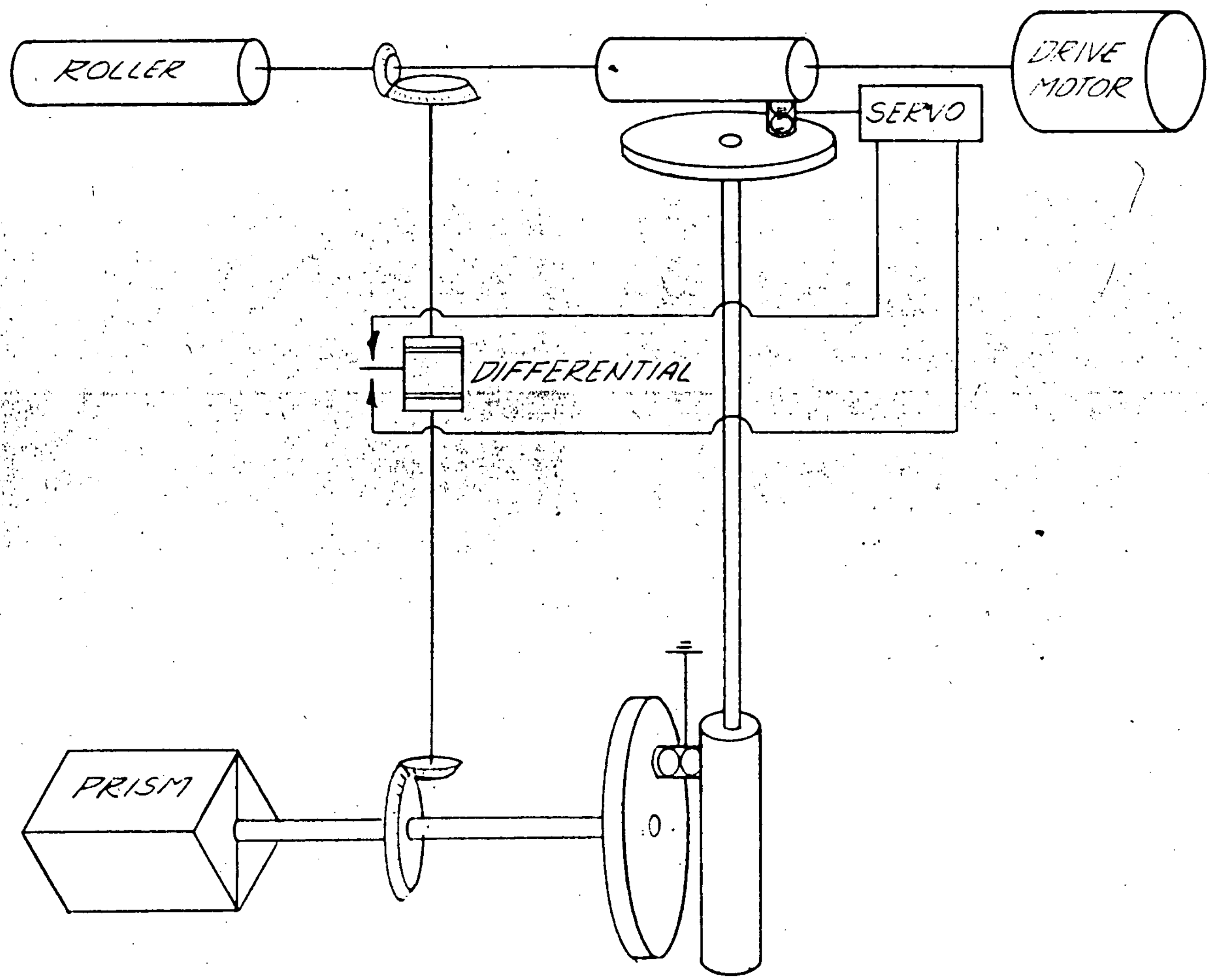
One approach which shows excellent promise is the use of a ball and disc integrator located at the film capstan roller and another at the prism shaft. The two integrators would divide the reduction ratio to the prism between them, and be coupled with a single stiff shaft running at intermediate speed. The built-in characteristics of this component are ideal for this application. The velocity error is exceptionally small when evaluated over small intervals of time. The ratio can be adjusted by control of ball-cage position. The input and output shafts are conveniently at right angles. Finally, they are compact, standard components.

It is desirable that the absolute ratio between film roller and prism be monitored and corrected automatically during operation of the camera.

It is sufficient to monitor at intervals of one prism turn. A promising method would be to count roller revolutions per prism turn and correct the ratio with the integrator ball cage input in small increments until the count is exactly equal to the design value of the shaft ratio. For example, an effective metering roller diameter of 2 inches requires an exact ratio of 48 to 1. Using pickoffs and computing techniques, the relative phase angle of a prism pulse is compared with each 48th roller pulse. The ratio error can be brought toward a null using a stepping motor on the ball cage input of one of the integrators.

There is an analagous mechanical approach to the ratio-monitoring system which also shows promise. This consists of a differential geared to the roller and prism with the exact 48:1 ratio built into the gearing. Any rotation of the differential output is a measure of ratio error; it would be detected by sensitive switches, and a correcting pulse fed to the ball-cage stepping motor. The gearing of the system carries low-level signal information only, and thus will not load the tight main drive with gear noise. Fig. 15.

Other methods of accomplishing the drive coupling are available, some having much promise because fewer components are required. Among these are 1. precision open loop friction drive with metallic cones (similar in function to bevel gears), 2. Fixed-center friction drives using a rubber-tired roller against a metallic roller (known as a "puck drive"), and 3. Monitored puck drive,



VARIABLE SPEED DRIVE
FEEDBACK THRU CONTACT SERVO

Fig. 15

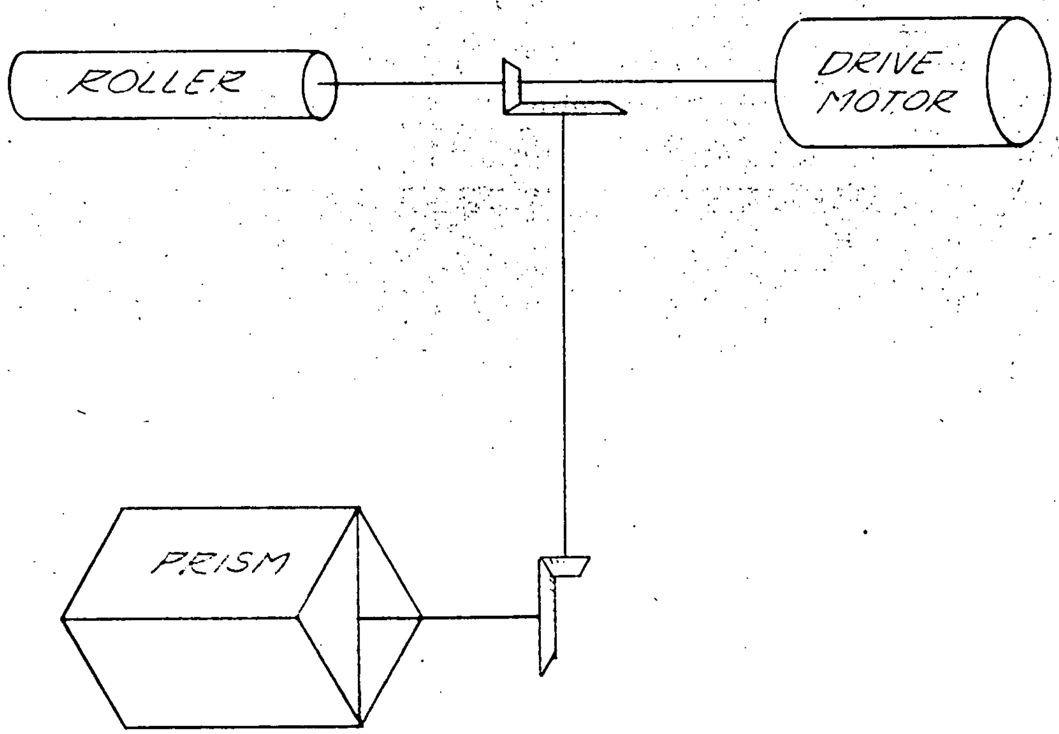
having a fixed-ratio mechanical feedback loop for longterm control of creep ratio. Figures 16, 17, 18.

The first of the above is an unfiltered open loop device depending on machining precision; the second is a filtered open loop device which depends on uniformity of load and control of ambient. The third system is immune to disturbances of any reasonable amount, but also depends somewhat on control of ambient due to the resilient elements of the filter.

The final choice of drive coupling between film roller and prism must result from study and development, and will be done with consideration of all problems of accuracy and reliability. We are confident that a suitable drive will result.

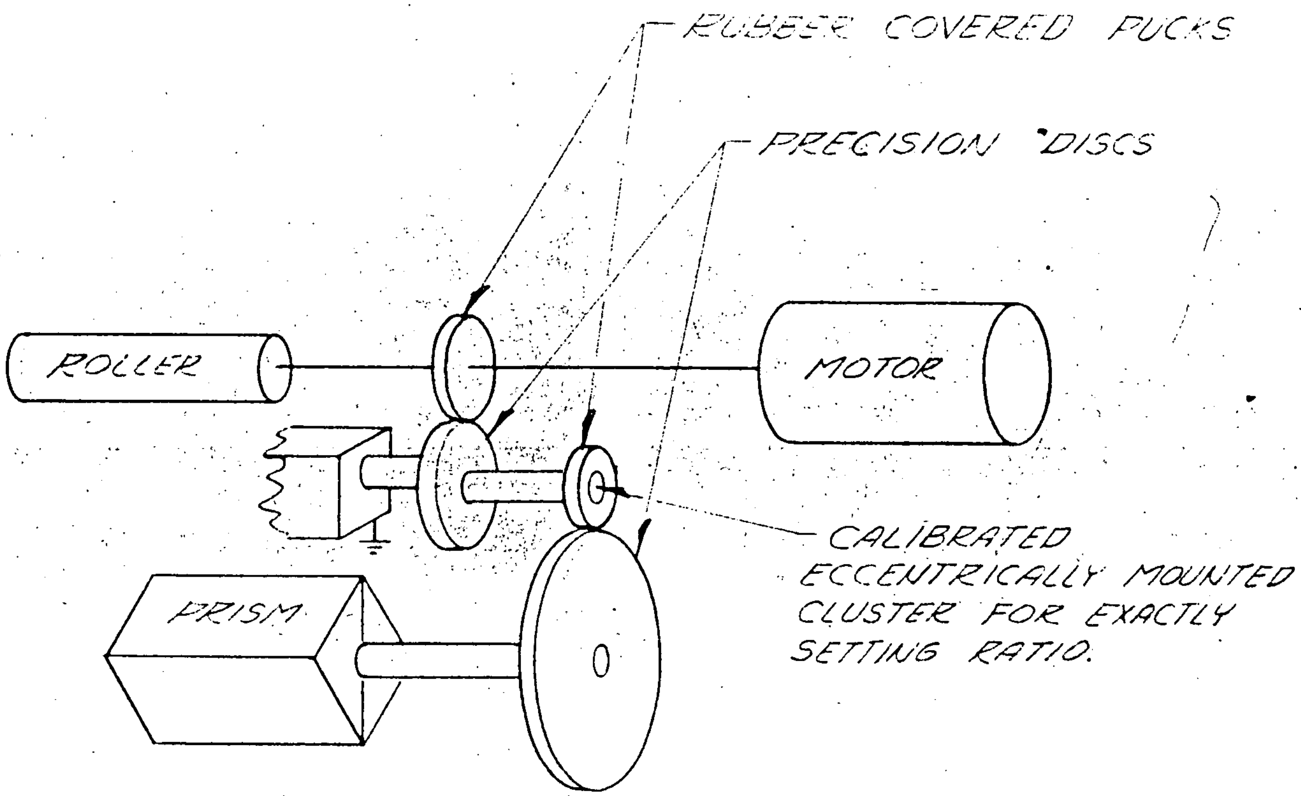
Film Metering

The accuracy of image and film synchronization depend not only upon the drive ratio but also on the behavior of the film relative to the metering roller. Using rubber in order to obtain good traction, there is always the problem of creep, which requires special attention. In order to maintain creep at a small, predicable level, the film feed and takeup functions are isolated by providing separate drives, (see Figure 4) also by incorporating tension stabilizing systems. This will insure that the



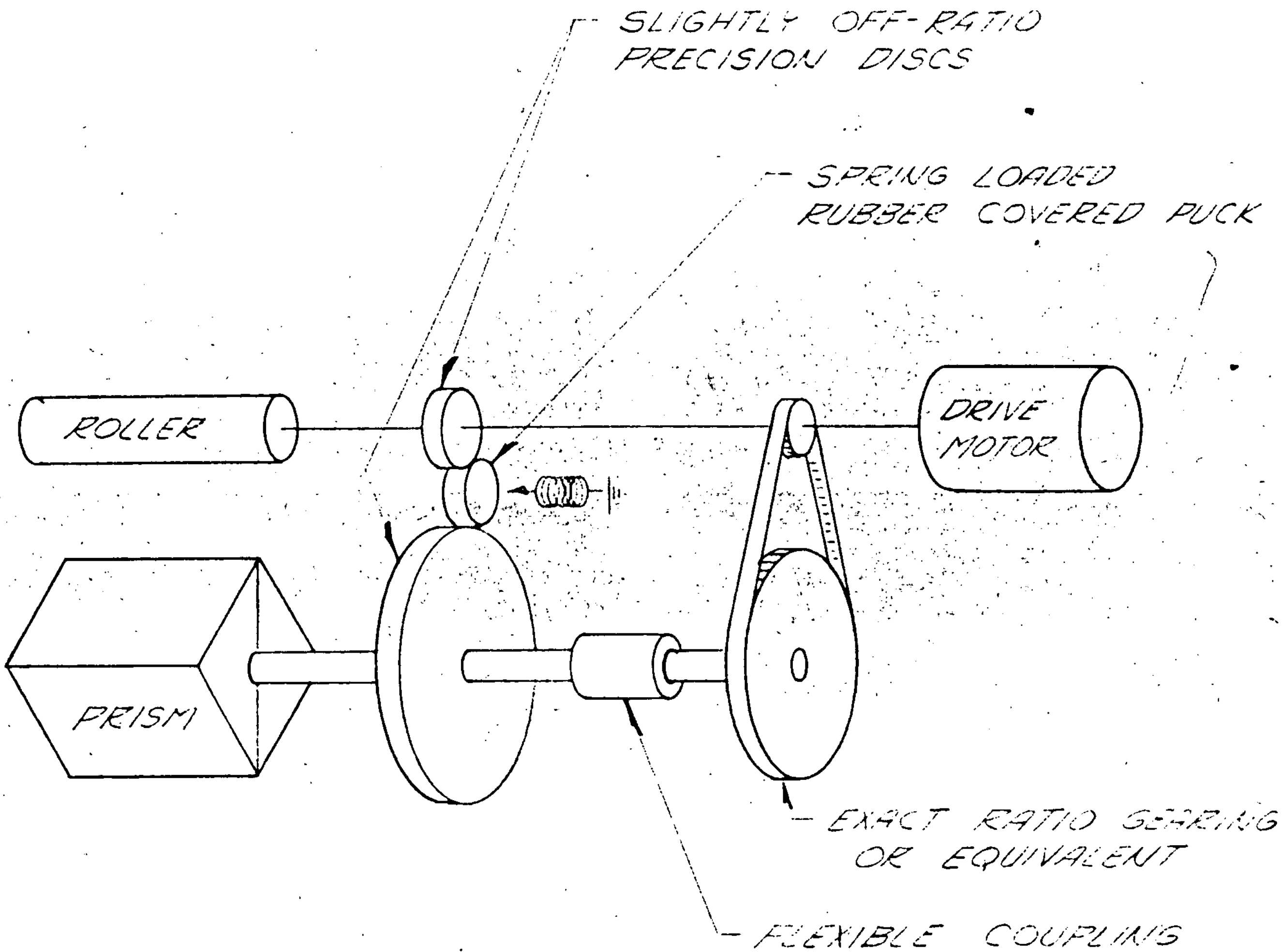
FIXED SPEED FRICTION DRIVE

FIG - 16



TWO STAGE PUCK DRIVE WITH PROVISION FOR SETTING EXACT RATIO.

FIG. 17



PUCK DRIVE WITH MONITORING FEED BACK LOOP

FIG - 18

load on the metering roller is constant and small regardless of the varying tension at the film spools.

The film metering motor is to be driven by a velocity servo motor and associated system which is described in Appendix II. The speed reducer system between motor and roller must be of excellent quality and will contain the elements of a mechanical filter to minimize density banding. While most of the problems in the camera system are aggravated when the running rate is high, the banding problem is worse at slow speeds and narrow slits.

There are two kinds of errors to be brought to a satisfactory low level. The low frequency accuracy is controllable through proper design of the control system, operating from the functional input of V/H, and by the velocity servo performance. The high frequency accuracy is controllable with suitable design of the speed reducer to eliminate troublesome gear noise, and by filtering. Fig.19 is a schematic of the complete film metering system, including the essential elements of the feed and takeup stabilizers, providing isolation for the main drive.

<u>Film Spool Arrangement</u>

When the problem of simplest film handling and threading is considered alone, it is seen that the arrangement should allow film to pass through the system without twists or changes of direction edgewise.

The figures 19 and 20 show the system configuration in such a simple form however impractical it might be for actual use because of its overall width. Fortunately the spool arrangement and design detail of the film enclosure can be readily suited to the space requirements of an actual or proposed, vehicle because of the continuous film feed. There is little effect on the system with the one exception: it is very important that the stabilized system center of gravity falls at the common center of the stabilization axes, and that there is compensation for film transfer from one spool to the other. The use of an auto-shifting magazine controlled by the stabilization system as described in Appendix III is most desirable because it eliminates the need for a moving counterbalance.

In exercising the choice of spool arrangement, proper consideration must be further given to accessibility for threading, and roller system simplicity. One of several promising practical configurations (Fig. 21) is an arrangement of spools on a common vertical axis above the camera with the compensating shift operating in the axial direction. The final choice must be made after considerable study and liaison during the design phase of the project.

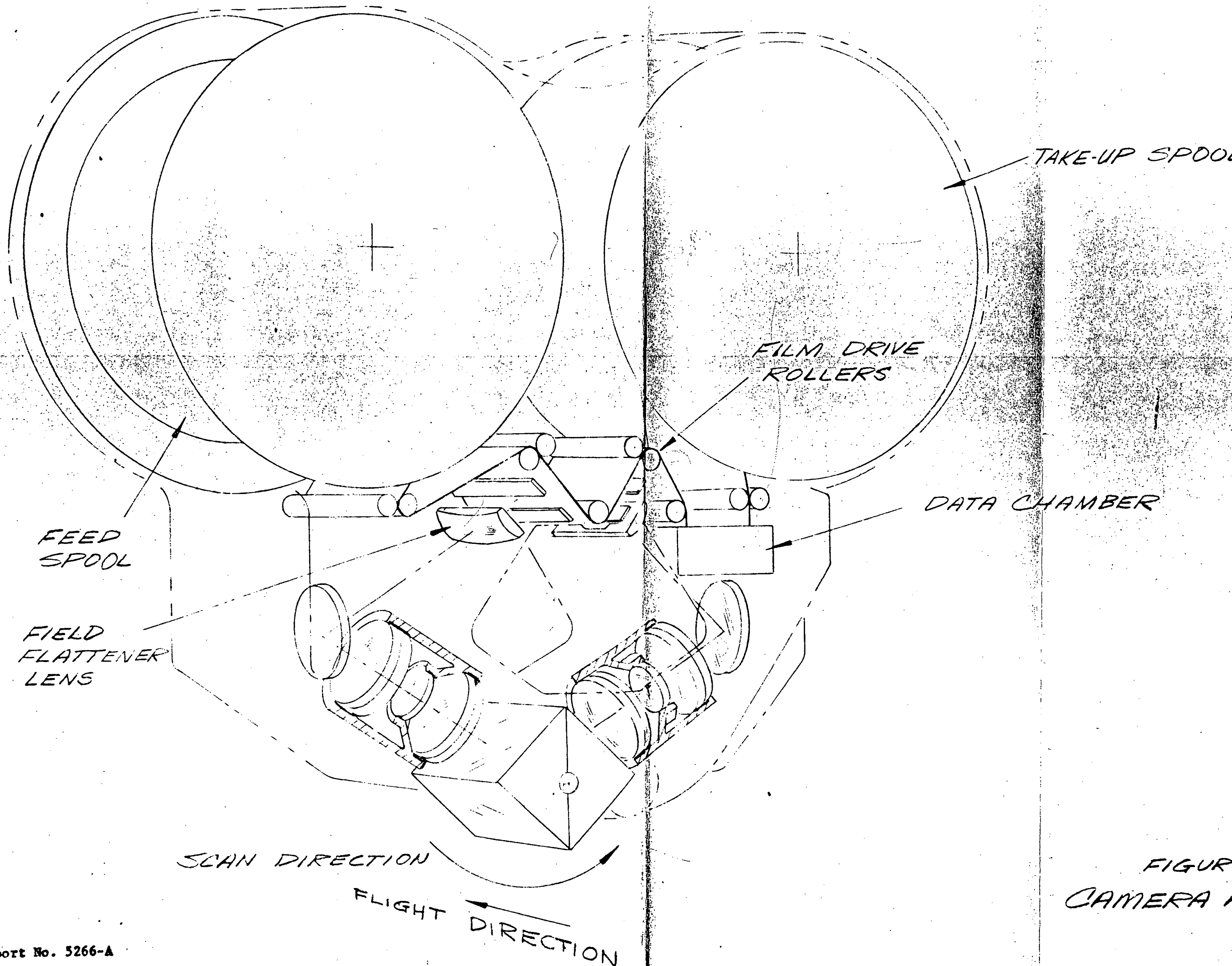


FIGURE 19
CAMERA ARRANGEMENT

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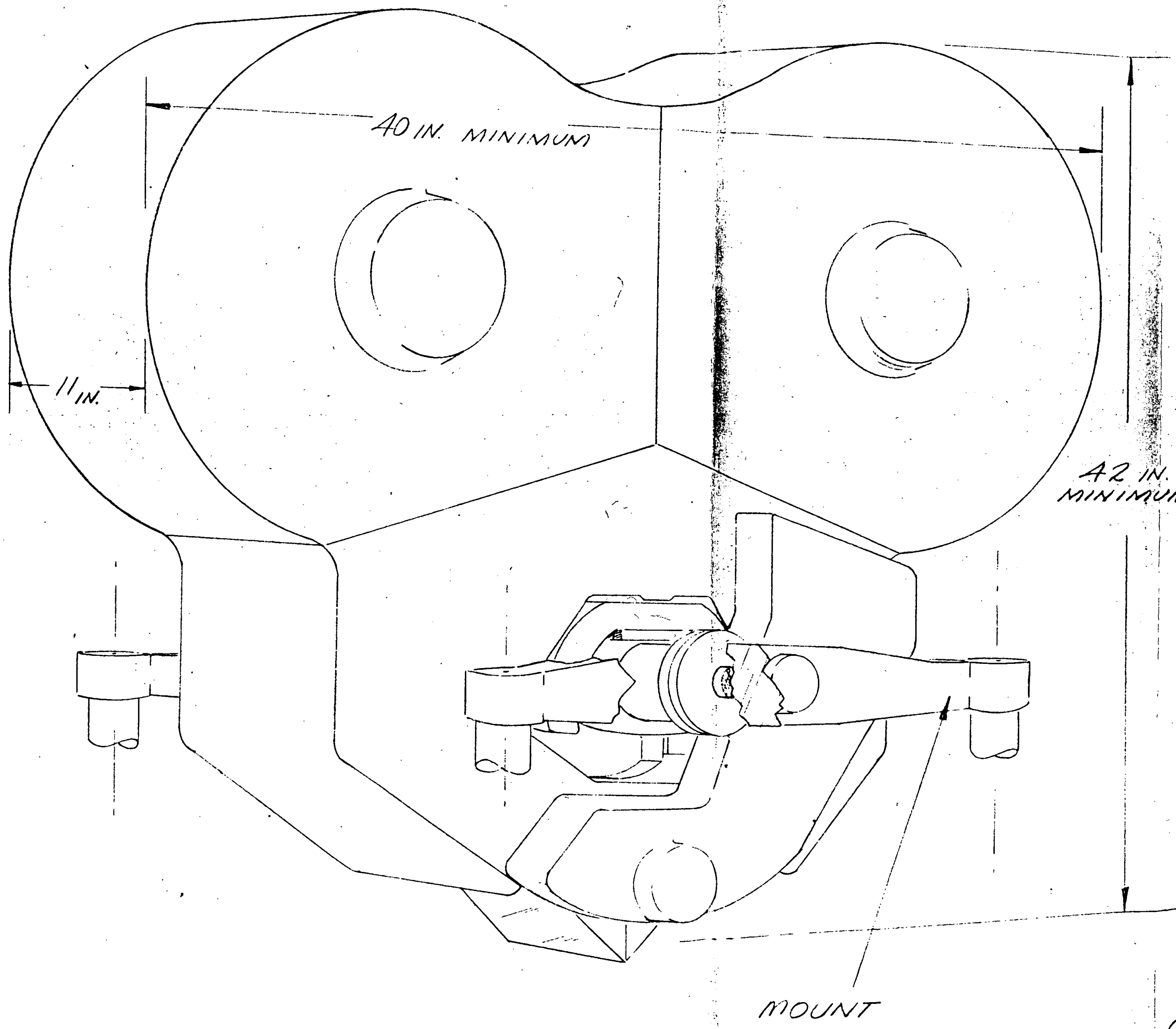

NOTES:
1. FORE AND AFT OVERALL LENGTH 21 IN.
2. SYSTEM WEIGHT 528 LBS (SEE TEXT)

FIGURE 20
CAMERA OUTLINE DRAWING
(THERMAL BARRIER NOT SHOWN)

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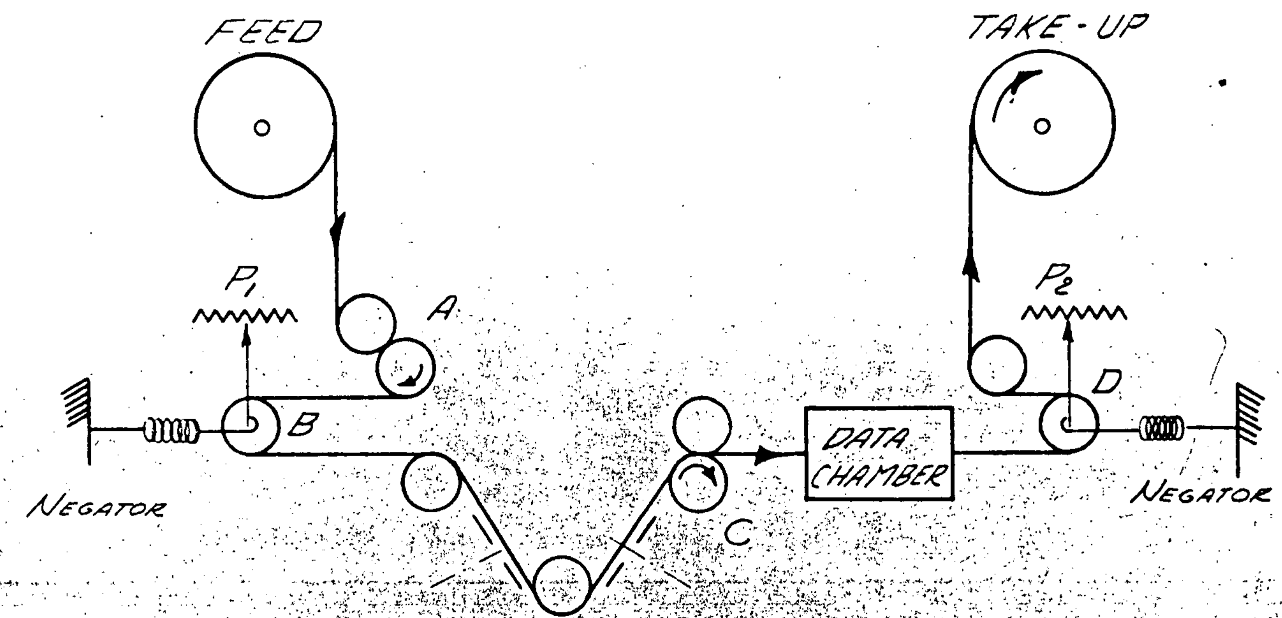

Feed Stabilizer	**A**	**Applied power from feed stabilizer velocity servo**
	B	**Constant tension feed signal roller**
	P_1	**Feed servo control signal potentiometer**
	C	**Applied power from main film drive velocity servo**
Take-up Stabilizer	**D**	**Constant tension take-up signal roller**
	P_2	**Take-up servo control signal potentiometer**
	E	**Applied power from take-up stabilizer velocity servo**

Fig. 21 Elements of Metering System

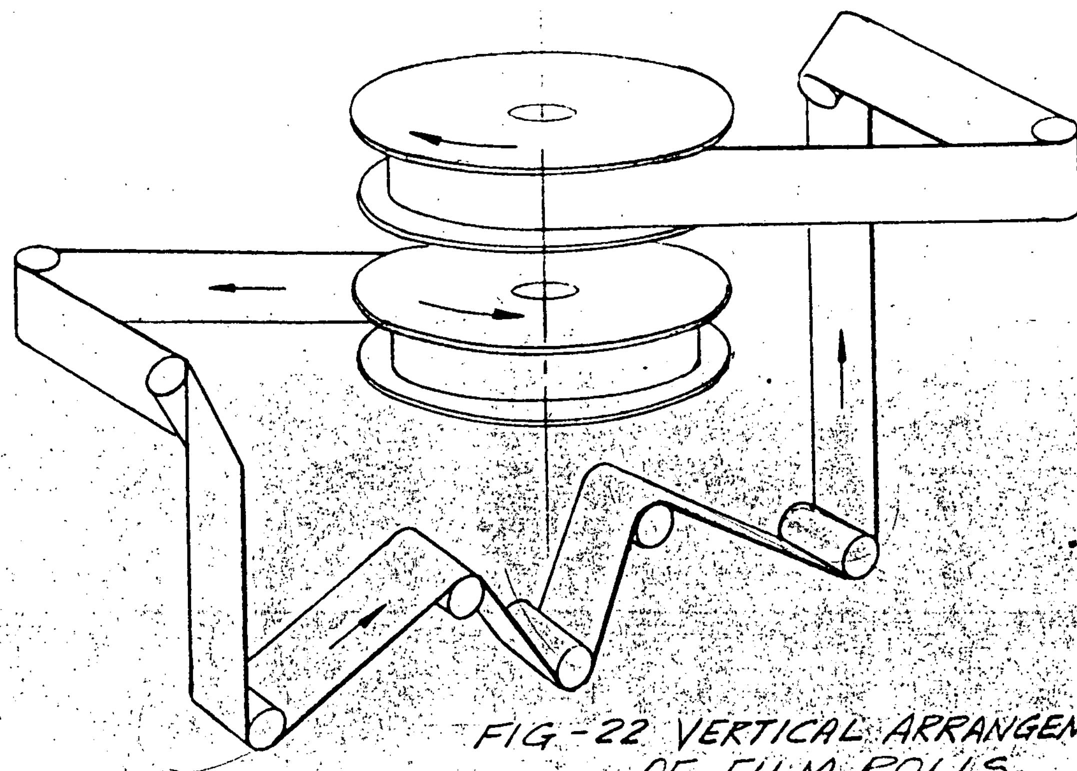

FIG-22 VERTICAL ARRANGEMENT OF FILM ROLLS

Data Recording

Further study must be given to this general problem. The optical system of the data printer is required to image the data upon the moving film with adequate synchronization accuracy to resolve the data and for a duration sufficient to properly expose the film. It is not considered a serious problem to accomplish this, with the possible exception of the 1000 cycle signal (at all film velocities). The configuration design should be more advanced than at present before knowledge of space for data chamber is available. Thus the need for liaison, and for more detailed development, is the cause for accepting the requirement at present as a design objective.

General Construction

It is very important to design for structural stiffness in the framework which is used to hold optical components in correct relative positions, and couple them to the point of attachment to the mount. The framework structure will be constructed using the best appropriate materials (least weight for a given stiffness) such as hollow magnesium castings and/or thin drilled-web structural elements.

The enclosing compartmentation and housing skin can be made light by thorough exploitation of molded plastic, and honeycomb-cored panels. Subsystems and components will be designed and selected with the weight requirement fully in mind. Excess weight can be eliminated even in the optics by using bonding techniques to simplify the prism and mirror mounts, by using sandwiched or webbed mirrors, and lightweight lens mounts. It should be noted that the mechanism proposed is free of intermittent motions, which means lighter structures because the reduced need for dynamic strength, and for counterweights.

A factor in the structure design is the reduction of vibration, through dynamic balancing of rotating parts where necessary, by vibration isolation, and again by design for stiffness of critical elements, with full attention to all these available measures from the inception.

The weight of the system, including controls and accessory equipment, mount, and cassettes but excluding the thermal barrier and film, is estimated to be 440 pounds maximum. However, the design goal will be a best effort for minimum weight.

ASSOCIATED SYSTEM COMPONENTS

Control System

The three major control elements previously discussed may logically be assigned to province of Chicago Aerial Industries for development in this team effort. These are

1. the operator's control panel
2. the exposure control system and
3. the film drive velocity servo.

These items are treated as a group in more complete detail in Appendix II provided by CAI.

Since these elements must precisely control fundamental camera functions and since some of these elements are to be incorporated within the basic camera structure, it is mutually recognized that the work is to be coordinated by subcontract control.

Stabilization & Environmental Barrier

The camera concept advocated is admirably suited to the preferred knuckle joint stabilization technique. This phase of development logically is assignable to Aeroflex Corp. In order to distribute the development load most effectively, and because of their previous experience in this field, the design of the environmental barrier is also included in this assignment. Detailed treatment of these components is included in Appendix III provided by Aeroflex Corp.

CONCLUSION

We claim for the proposed design the following:

1. Efficient duty cycle
2. Fixed function I.M.C.
3. Fixed slits
4. Continuous film transport
5. Knuckle joint stabilization
6. Elimination of sequential system control problems
7. Minimum bulk
8. Minimum weight
9. Simplicity
10. Reliability

INTERPRETATIONS, DEVIATIONS, AND
EXCEPTIONS TO THE SPECIFICATION

3.4.5.3	Lens field 9 x 9 - excepted; maximum field is required.
3.4.5.9	An AWAR of 100 on Type SO1182 film is a design objective.
3.4.6	Except that maximum slit opening is 5/8", limiting the exposure time to 1/120 sec. maximum at the shortest interval time of 1 second.
3.4.11.7	Excepted - Vacuum platen not desirable; film to be held flat in the focal plane by means permitting continuous feed.
3.4.11.8, 3.4.11.9, 3.4.12	Design Objective, see text.
3.6.13	Design Objective - Routine maintenance procedures may be desirable at more frequent intervals.

Refer to Appendix III for further discussion of exceptions.

Programming for Reliability

Our present high standards of reliability have been achieved through the close cooperation of our engineering, production, quality control and field service personnel.

A list of representative Government Contracts is attached. We estimate (using the appraisal methods advocated by the American Society for Quality Control) that our overall reliability rating in this government development work lies between 85% and 90%.

In the design and development of the MA-2 Bombing System (B.D.H.S.A.), for example, where reliability was very tightly controlled, we achieved a reliability of 95-97%.

The prototype models of the Y-4 and MA-2 bombing periscopes furnished by Perkin-Elmer were durable and useable long beyond their expected lives and after very severe testing. In each case, after years of production, the last periscopes off the manufacturing lines require very close examination to find any change from the prototypes originally supplied by the Perkin-Elmer Corporation.

Our Recording Optical Tracking Instruments (R.O.T.I.) are designed and built to have a normal operating life of at least ten years with a minimum of maintenance. One of these equipments has now been operating for over two years, without failure under extremely bad field conditions.

Perkin-Elmer firmly believes that reliability is built into each product at its inception. The design we advocate in this proposal, for example, avoids the use of shutters, intermittently operating film transport mechanisms and rapid accelerations and decelerations of the film. These are all elements known to have high failure ratings.

In our Government contract work, our Engineering Department maintains and utilizes the services of a fully equipped Quality Control Section. A complete description of this organization, its personnel and procedures is contained in our Quality Control Manual, which has been reviewed by the New York Air Procurement District. This manual is available on request.

In addition to the above, we would, on a project of this magnitude, assign to an engineer definite responsibility for the reliability of newly procured parts and components and charge him with the duty of instituting and reporting on such tests as are required to establish the correct routine maintenance procedures.

It is possible, by virtue of mature basic design, good choice of components, exceptionally tight quality control and close engineering monitoring of the initial field tests to produce a reliable and durable prototype. To achieve maximum reliability, however, continued close liaison between the manufacturer and the testing agencies is required, plus periodic refurbishing evaluation and field modifications of the prototype. This program extension would permit the preparation of more detailed operating instructions for field use and establish an effective preventive maintenance procedure. The Perkin-Elmer Corporation would welcome the opportunity to participate in such a program extension. We have found this procedure most effective in satisfactorily completing similar projects.

APPENDIX I

LIST OF REPRESENTATIVE CONTRACTS

Agency or Prime Contractor	Description	Contract No.
AF	Design and build 023 Radar Mapping Camera for Fairchild (Confidential)	W33-038-ac-13431
General Mills (AF subcontract)	Design and build Y-2 Bombing Periscope	
General Mills (AF subcontract)	Design and produce Y-4 Bombing Periscope	
AF	BDHSA Bombing System- (Confidential)	W33-038-ac-21103
AF	Design and build experimental Periscope Fighter Sight. Sight has been flight-tested at Eglin Air Force Base (Confidential)	AF 33(038)-7509
AF	Design and build Experimental Periscope. Periscope used for tests in conjunction with prone position flying.	AF 33 (616)-233
AF	Design and build Transverse Panoramic Mapping Camera. Camera featured horizon-to-horizon coverage. (Confidential)	AF 33 (038)-1238
AF	Lightweight Lens Study-study feasibility of decreasing weight in large Aerial Photographic Lenses. Built 48" f/6.3 Lens, cutting weight from 180 lbs. to 90 lbs.	AF 33(038)-23063

Agency or Prime Contractor	Description	Contract No.
AF	Investigation of automatic computing techniques for use in optical design.	AF 33(038)-10836
Navy	MK-13 Fighter Sight	Nord 13473
Navy	Production prototypes of MK-13 Fighter Sight (Confidential)	Nord 15596
AF	Development of automatic-focus control for large Aerial Photographic Lenses.	AF 33(600)-23271
AF	ROTI-design and construct large Recording Optical Tracking Instrument (large theodolite) for use on missile test ranges	AF 33(600)-26666
AF	TPR-design and construct large long focal length camera	AF 08(616)-3
AF	Study of manufacturing techniques for producing aspheric optical elements	AF 33(616)-21111
Army	Design and build Thermal Image Viewer	DA-44-009-ENG-1744
AF Industrial Research Lab. (AF subcontract)	Reconnaissance Device (Secret) Optical design and construction of Simulator System	AF 33(616)-2031
AF	Airborne Tracking Device (Confidential)	AF 08(616)-30
Navy	Experimental Infrared Scanning Device (Confidential)	Nord 16139
AF	Study on High Temperature Measurement by Radiation	AF 33(600)-30130

Agency or Prime Contractor	Description	Contract No.
Princeton University	Design Study and Manufacture of Solar Telescope	
AF	Design and build Automatic Patrol Spectrograph	646610
AF	Research and development-Passive Infrared Warning System (Secret)	AF 33(600)-32295
Navy	Design and build Infrared Reconnaissance Device (Confidential)	N-163-4721
Army	Design Airborne Infrared System (Confidential)	DA-36-039-SC-73064
AF	Gas Radiation Pyrometer	AF 33(600)-30130
General Electric	Produced Model 103 and 145 Camera Attachments for K-19 Fighter Sight	
IBM	Produced optics for AN/ASB-4 Bomb Sight	
General Mills	Produced optics for Y-4 Bomb Sight	
Chicago Aerial Industries	Produced Aspheric Lens System	
Norden	Produced ASB-1 Bomb Sight Optics (including prototype design)	
Hughes Aircraft	Domes, Missile Head	TOP 545600-93D
Smithsonian Institution	Satellite Tracking Cameras and Film Back-up Plate	
Various	Miniature Cooling Systems for Laboratory and Airborne Cooling to Liquid Nitrogen Temperatures	

Agency or Prime Contractor	Description	Contract No.
AF	ROTI, Mark II (Radar Optical Tracking Instruments) for Patrick Air Force Base	AF08(606)-1047
AC Spark Plug Division (Gen. Motors Corporation)	Azimuth Alignment Theodolites	AF04(645)-19
AC Spark Plug Division (Gen. Motors Corporation)	Initial Alignment Theodolites	AF04(645)-19
AF	Military Infrared System (Secret)	AF33(600)33948

REPRESENTATIVE LIST OF P-E LENS DESIGN

FOCAL LENGTH	f/RATIO	NO. OF ELEMENTS	FORMAT
16mm	f/2.5	8	16mm or .625" diagonal
16mm	f/1.5	8	16mm or .625" diagonal
25mm	f/2	6	16mm frame
50mm	f/1.9	6	16mm frame
50mm	f/4	4	16mm frame
30 to 150mm	f/2.7 to f/4.7	10	.627" diagonal Zoom Lens

Note: Aperture remains constant throughout Zoom range at any stop between f/11 and f/4.7, and above f/4.7 tapers from f/2.7 at the short focal to f/4.7 at the long focal length.

FOCAL LENGTH	f/RATIO	NO. OF ELEMENTS	FORMAT
25mm	f/1.5	8	Single Frame 35mm
25mm	f/2.5	8	Single Frame 35mm
50mm	f/2	6	Single Frame 35mm
6"	f/4	4	Single Frame 35mm
150mm	f/.71	9	Single Frame 35mm
1-7/8"	f/4	6	8.4x and 13.9x enlarger lens (2 ratios)
3"	f/1.5	8	2-1/4" x 2-1/4"
3"	f/2.5	8	2-1/4" x 2-1/4"
4"	f/2	6	2-1/4" x 2-1/4"
12"	f/4	4	2-1/4" x 2-1/4" (Aspheric)
6"	f/1.5	8	4-1/2" x 4-1/2"
6"	f/2.5	8	4-1/2" x 4-1/2"
6"	f/4	6	4-1/2" x 4-1/2"
6"	f/2.5	8	4-1/2" x 4-1/2" (Aspheric)
12"	f/2.5	8	9" x 9"
12"	f/4	6	9" x 9"
36"	f/8	5	9" x 9"
36"	f/5.6	7	9" x 9"
40"	f/5	7	9" x 9"
48"	f/6.3	5	9" x 18"
96"	f/8	5	18" x 18"
144"	f/8	5	18" x 18"
2-1/2"	f/4	6	Double Frame 35mm (Enlarger Lens)
2-1/2"	f/4	6	18 x 24mm (Enlarger Lens)
4"	f/4	6	2-1/4" x 2-1/4" (Enlarger Lens)
6"	f/4	6	4-1/2" x 4-1/2" (Enlarger Lens)
36"	f/10	5	18" x 18"

FOCAL LENGTH	f/RATIO	NO. OF ELEMENTS	FORMAT
36"	f/4	7	9" x 18"
60"	f/6	6	2-1/4" x 2-1/4"
48"	f/6	6	1.9" dia.
24"	f/3.5	8	9" x 18"
6"	f/1.5	8	35mm
24"	f/8	5	9" x 18"
36"	f/5.6	8	9" x 9"
36"	f/5.6	9	9" x 18"
100"	f/3.5	6	2-1/4" x 2-1/4"
48"	f/8	5	18-1/2" x ______*
12"	f/12	5	9" x 9"

* Panoramic Film strip of great length passes across a 2" wide focal plane shutter x 18-1/2 high.

PERSONNEL ASSIGNMENTS

In the event Perkin-Elmer were to be awarded the contract, assignment of personnel would probably be made as follows:

The work would fall within the scope of the Engineering and Optical Division. [redacted] is the General Manager of the Division which has its Headquarters in Norwalk, Connecticut. Dr. Miller is a member of the Scientific Advisory Board of the USAF. STAT

The program will be under the management of [redacted] [redacted] Director of Engineering. [redacted] has been the responsible engineering manager for all instruments produced by the Engineering and Optical Division since its formation. STAT STAT STAT

[redacted] will probably be assigned to lead the operational phases of the project. [redacted] is an authority on panoramic cameras and high acuity, low contrast systems. He has been project engineer on several camera systems including the Model 151 and the Model 501 Panoramic Cameras. STAT STAT

The optical design will be handled by [redacted] [redacted] Chief Engineer of the Optical Design Group, and his chief assistant, [redacted] are nationally recognized authorities in this field. STAT STAT STAT

It is expected that [redacted] will avail himself of the services of Messrs. [redacted] STAT STAT [redacted] is Chief Engineer of the Optical Research and Development group and has been largely responsible for the development and production of high acuity lenses and special aspherics. Mr. [redacted] is in charge of the Systems Development Group, and is in charge of the ROTI's, other opto-mechanical systems, and infrared-electronic systems.

It is also expected that [redacted] Senior Engineer who has done considerable work on Cameras and Shutter Systems will participate. In addition, the project engineer will call upon other senior, junior and test engineers within the division as job requirements dictate.

Senior Engineers will be assigned to monitor and report on the work of the two major subcontractors and one engineer will be assigned to establish test procedures and report on the reliability of the components used and of the various assemblies.

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APPENDIX II

CHICAGO AERIAL INDUSTRIES, INC.
Melrose Park, Illinois

PROPOSAL FOR
PORTIONS OF THE
E-2 PANORAMIC CAMERA SYSTEM

Submitted to: The Perkin-Elmer Corporation
Post Office Box 730
Norwalk, Connecticut

Attention: [redacted]

STAT

May 1958
Rev: June 1958

THE ENCLOSED INFORMATION

is prepared and submitted in a spirit of confidence. The discussion, ideas, and disclosures herein are to be considered as proprietary information of this company, which without specific written permission, are not to be used, reproduced, transmitted or divulged in any manner which this company may consider as detrimental to its interests.

I N D E X

INTRODUCTION

Chicago Aerial Industries, with its well-known leadership in the aerial reconnaissance field, proposes to utilize its experience in furnishing the control functions of the E-2 Panoramic Camera System. This experience has been gained through a number of reconnaissance projects, many of which required the integration of several camera types and electronic control components. Complete photographic system concepts as found in the F9F-8P, A3D-2P, F8U-1P, and P6M aircraft are representative examples of Chicago Aerial Industries' system responsibilities.

Chicago Aerial Industries has also developed and furnished specific reconnaissance items such as the KA-30 and KA-18A Cameras and various viewfinders, including the one used in the RF-101 aircraft. Also, a number of high acuity 70mm panoramic cameras were furnished to the Air Force.

These contributions to the state of the art have been made with the highest degree of quality and reliability consistent with good design. It has been the policy of Chicago Aerial Industries to investigate completely the reliability concepts involved in an end item and present conclusive guarantees as to operating life and recommended maintenance procedures.

In order to accomplish the objectives presented herein, Chicago Aerial Industries intends to organize a project team composed of personnel well versed in the arts of aerial reconnaissance and precision electro-mechanical design.

SCOPE

The equipment proposed herein is intended to be incorporated into or used with the E-2 Panoramic Camera to be built by the Perkin-Elmer Company.

Chicago Aerial Industries proposes to furnish three major systems for the Panoramic Camera.

1. The Camera Control System
2. The Automatic Exposure Control System
3. The Velocity Servo Drive System

These three systems will be designed and fabricated to meet the requirements of Exhibit WCLR-481 as amended by Note A. Systems 2 and 3 will also be furnished to be included in the overall confines of the camera proper.

THE CAMERA CONTROL SYSTEM

The basic control of the Panoramic Camera System will be provided by a remotely located control panel. This control center will provide all of the necessary control functions for the Panoramic Camera. The required functions are the application of master power, starting and stopping the camera operation, selecting primary picture taking rate, and regulating the exposure of the film. Operational status of the camera system must be indicated such as readiness, proper operation, number of exposures made, and a low film indication.

These objectives of control for the Panoramic Camera System will be provided by means of a compact rack and panel type control unit. The configuration will be as shown in Figure 3000-84-1. The function of the various controls will be as follows.

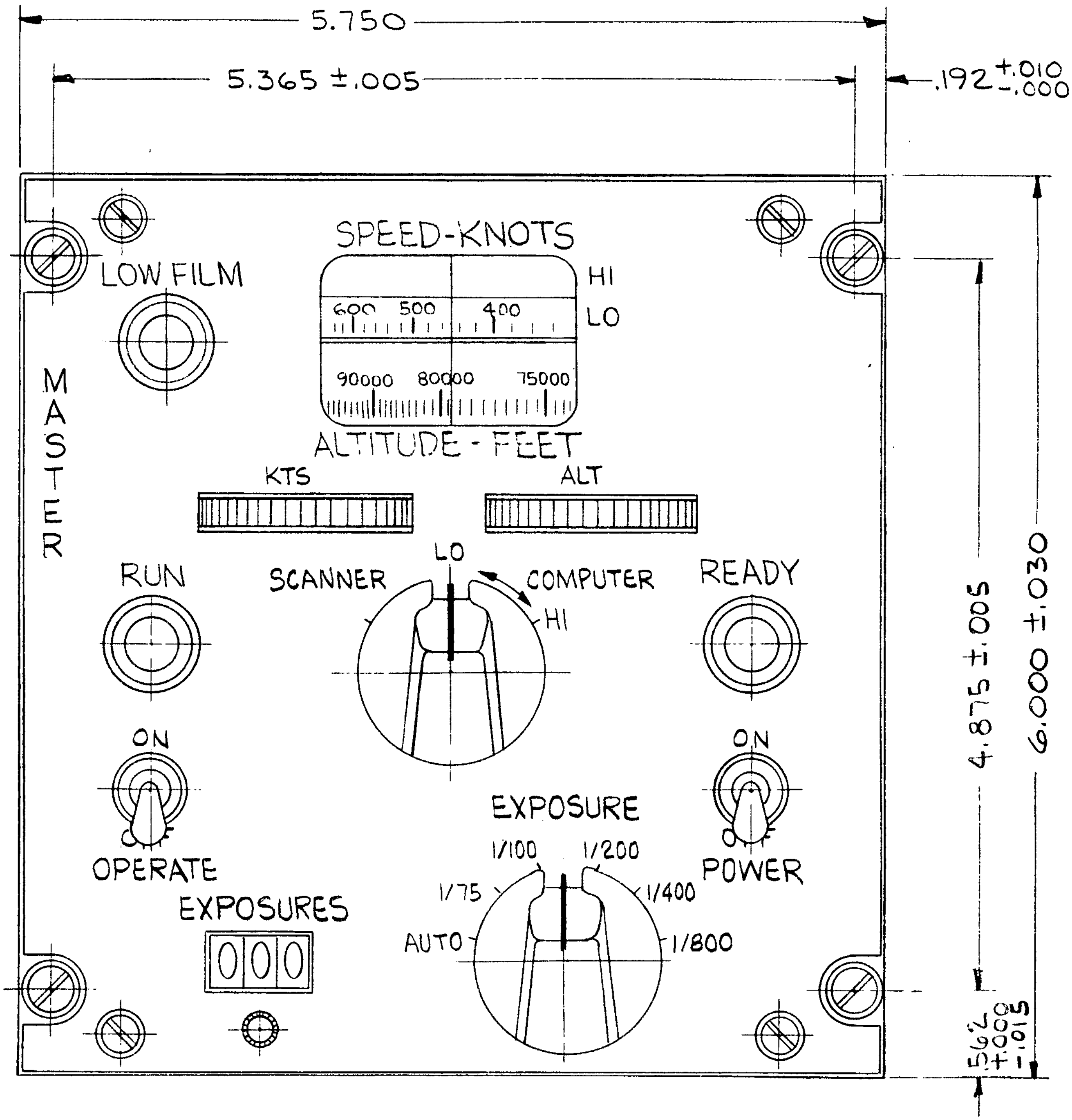
The master power switch completes the power circuitry to the camera. System readiness indication is provided by the green ready lamp which will light when the stabilization of the camera is complete.

The parameters of velocity and altitude which govern the picture taking rate, are set into the photographic system by means of the knots and feet dials together with the applicable scales. A mechanical mask will aid in selecting the velocity setting in the high or low ranges. Provision is also made for other control systems to be used in establishing the picture taking rate. It will be possible to select an automatic mode of establishing this rate. This can be accomplished by changing the mode selection switch from the "high or low computer" to "scanner" position. The details of establishing the picture taking rate will be discussed subsequently.

Completely automatic control of the relative exposure is provided by the "auto" setting of the exposure selection knob. It is also possible to set in a specific effective exposure time as indicated by the other positions of the selection knob.

Operation of the camera is initiated by means of the operate switch. During the picture taking, the amber scanning indication lamp will light and go out when the scan cycle is complete indicating that the camera is running. Thus, normal operation is indicated by a blinking light. If the film supply is interrupted, either by being empty or tearing, the lamp will stay on until the condition is remedied. A film pile-up will also be revealed as a film failure by the steady on lamp condition; however, the film drive power will also be stopped to prevent damage to the film transport system.

A three digit resettable counter is used to indicate the number of exposures made. An indication of the supply of film will be provided by a red low film lamp which will light when there are approximately 100 feet of film or about 16 exposures remaining in the film feed cassette.



NOTES:

1. DEPTH OF UNIT, FROM MOUNTING SURFACE TO BACK END OF COVER IS 5" MAX.
2. CONNECTOR - MS3102A-28-12P TYPICAL

FIGURE 3000-84-1

CONTROL PANEL FOR PANORAMIC CAMERA

THE AUTOMATIC EXPOSURE CONTROL SYSTEM

The control of exposure in the Panoramic Camera can be operated in either manual or automatic modes. In either case, the effective exposure time will be determined by the width of a variable slit and the relative velocity of the film across the slit so that

$$W = t\,V_f \qquad (1)$$

where:
- t = exposure time, seconds
- W = width of slit, inches
- $*V_f$ = velocity of film across slit, inches per second

*An expression for the value of V_f can be found in the discussion of the velocity servo.

Having established this relationship, it will be necessary to use this slit width to solve the basic exposure equation which is

$$B = \frac{K\,f^2 c}{S t T} \qquad (2)$$

where:
- B = terrain brightness, foot lamberts
- K = a constant with a range of 1 to 2, depending on emulsion characteristics which for microfile type emulsion can be taken as 1.5
- f = diaphragm opening, f stop (5.6 in this case)
- c = filter factor, usually 2 for a yellow filter
- S = speed of the emulsion, Weston

t = equivalent exposure time, seconds
T = transmission of the glass system in the objective which is assumed to be 60% for a lens of this type

solving this for the slit width we have

$$W = 78.2 \frac{C}{S} \cdot \frac{V_f}{B} \qquad (3)$$

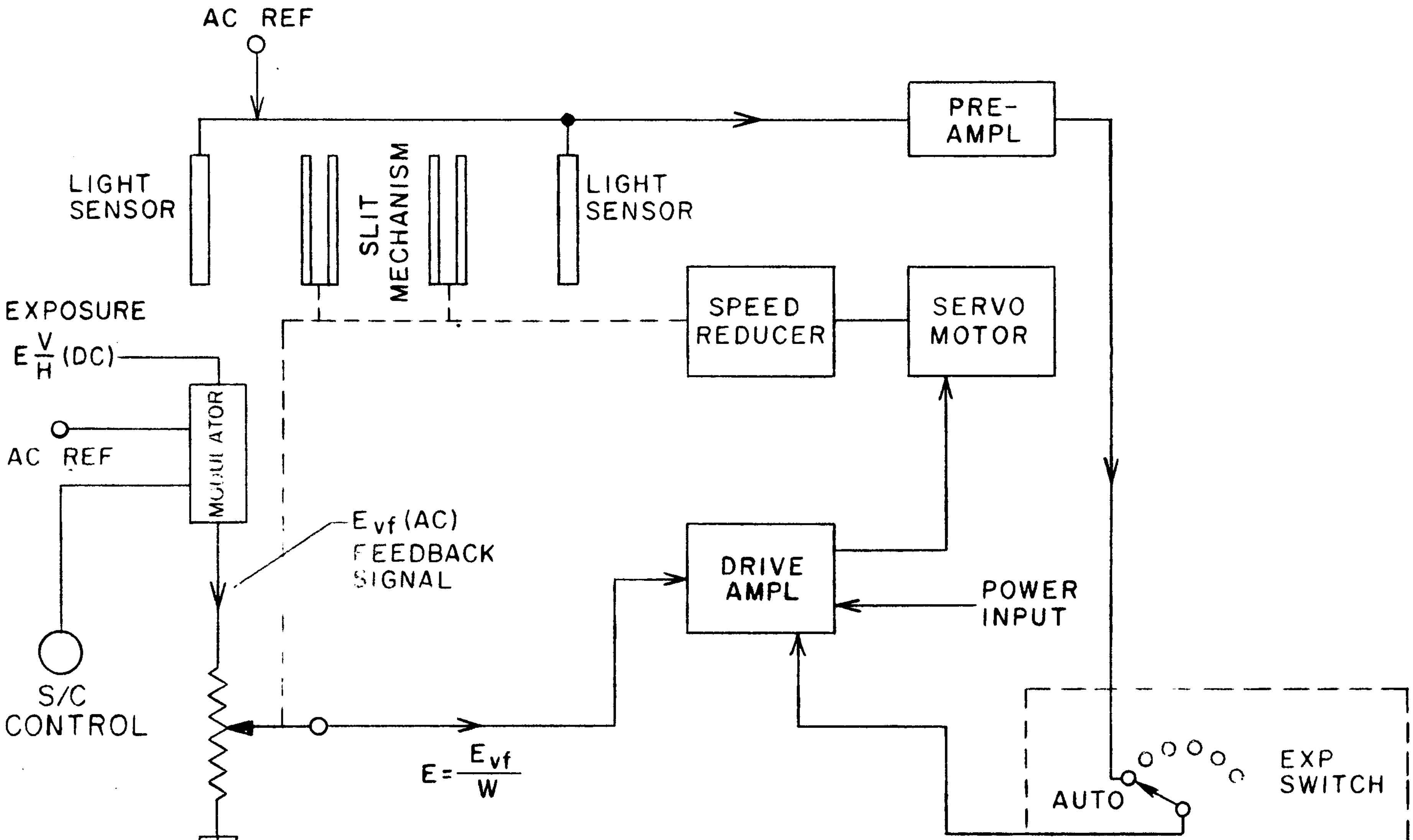
The accuracy of the solution of equation (3) can be established by investigating the sensitometric characteristics of the particular emulsion being used. Basically, the various texts on this subject relate the resolution capabilities of the emulsion to the latitude. In the case of the microfile type emulsion (SO1182) a latitude of 2 to 1 can be expected. This requires a minimum of one full stop accuracy assuming that all other factors of exposure are perfect. It has been the experience of Chicago Aerial Industries to use a maximum error of one-half f stop in a high acuity exposure control system.

The proposed exposure servo will use a cadmium sulphide photo electric cell for light level sensing. This type photo cell has the following advantages: 1) extreme sensitivity, 2) good temperature stability, and 3) long term stability. An additional advantage is obtained from the fact that the cadmium sulphide cell is a photo resistive device. An AC output can be obtained by applying AC reference to the cell. This eliminates low level DC to AC modulators.

A block diagram of the exposure servo is shown in Figure 3000-84-2. A DC voltage, $E_{V/H}$, which is proportional to image velocity is applied to a modulator containing resistive dividers. The output of the modulator is an AC voltage E_{Vf}, proportional to image velocity. This voltage is applied to a function pot mechanically connected to the slit mechanism whose slider voltage is proportional to $\frac{1}{W}$. The S/C constant is inserted by a control on the modulator unit.

The photo electric cell is energized by an AC reference voltage 180° out of phase with the voltage used to drive the V_f modulator.

The resulting brightness signal is summed with the E_{Vf} and the brightness voltage. The error voltage is used as a signal in the servo motor drive amplifier. At null a solution of the exposure equation is obtained.



EXPOSURE SERVO
FOR
PANORAMIC CAMERA

FIGURE 3000-84-2

Sanitized Copy Approved for Release 2010/12/13 : CIA-RDP74B00752R000100100001-4

THE VELOCITY SERVO SYSTEM

The picture taking rate of the Panoramic Camera is to be governed by the parameters of reconnaissance vehicle velocity and the height of the vehicle above the terrain so that an overlap of 55% will occur between successive pictures. Furthermore, in order to reduce as much as possible the image degradation due to target movement in the image plane, compensation must be made for the forward motion of the vehicle. This image motion compensation (IMC) is established by moving the optical axis of each of the lenses parallel to the flight line as previously discussed. These criteria establish the need for a precise and reliable servo mechanism to guarantee synchronism between the various optical and mechanical components.

A basic command voltage, $E_{V/H}$, which originates from the computer in the system control panel, is required to establish the primary rotational input to the camera mechanism. This voltage will be related to the velocity and height of the vehicle as follows:

$$E_{\frac{V}{H}} = K \frac{V}{H} \qquad (4)$$

where: K = a constant depending on servo design considerations
V = velocity with respect to ground, knots
H = height above terrain, feet

The constant K will be optimized to obtain a high and low velocity range. A single value would not allow the accuracy required of this high performance servo mechanism.

The operational envelope of the camera is shown in Figure 3000-84-3 which extends over a V/H range of 0.003 to 0.1 knots per foot. This range will be available over an altitude range of 20,000 to 100,000 feet and a velocity range of 300 to 2,500 knots; however, $E_{V/H}$ will be limited to produce a maximum of one complete picture per second.

In view of the high acuity requirements of the Panoramic Camera, it would be well to consider the accuracy of the velocity servo system. Since the servo mechanism will control primarily the film velocity across the variable slit, all errors in the camera system will be manifested as a function of this theoretical velocity. The pictorial effect of these errors would be to increase or decrease the overlap and, more important, degrade the terrain recognition due to image blur.

In considering the effect on overlap, we have the following. As previously stated, the rotational speed of the prism with respect to the film velocity will ultimately be established as an exact ratio. Thus, the actual film velocity will determine the overlap error in the relation

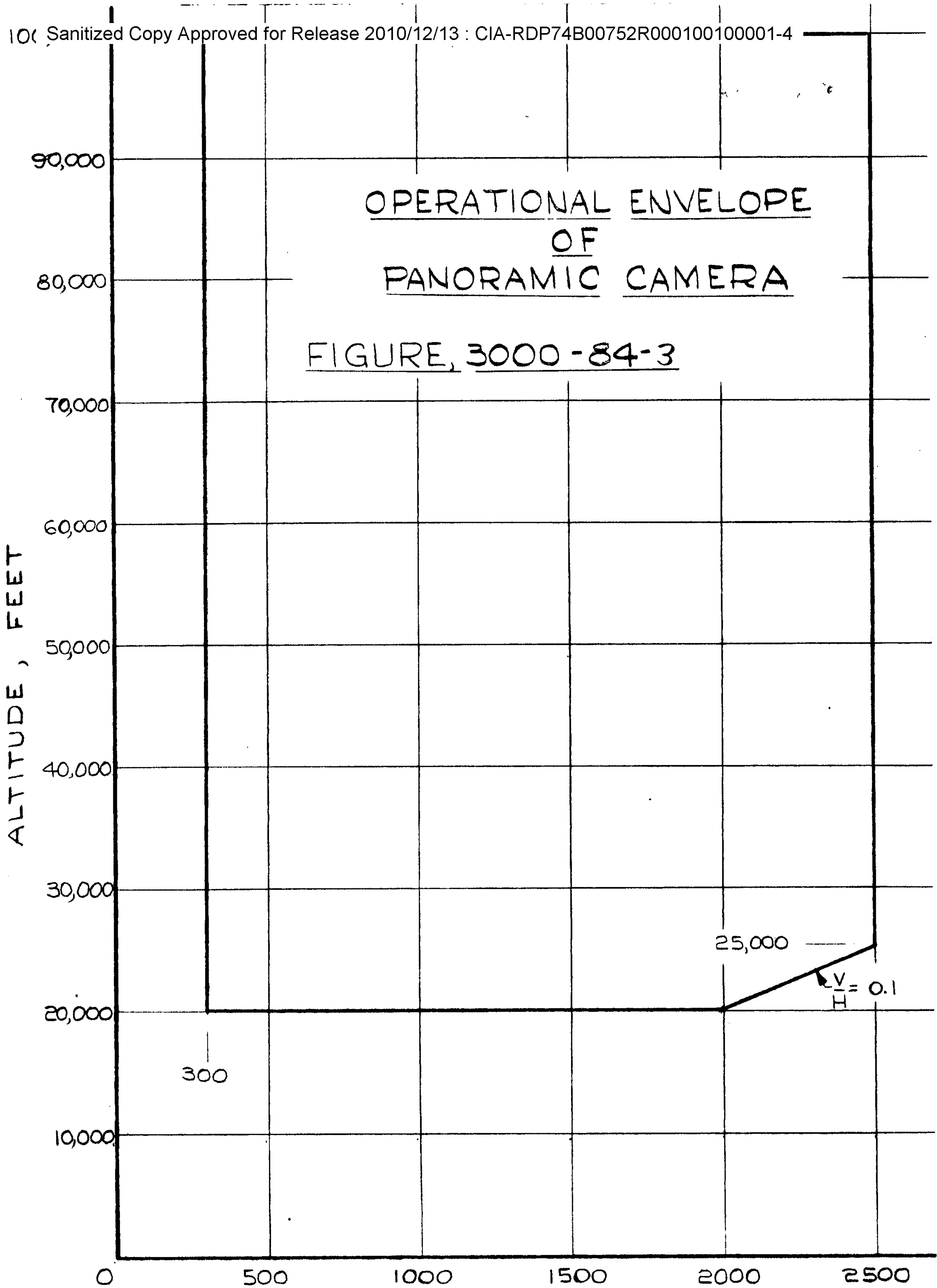
$$V_f = \frac{339\ V}{H\ (1-\phi)} \qquad (5)$$

where: V_f = film velocity, inches per second
ϕ = overlap, decimal

This relation is based on the basic picture taking rate for vertical photography and length of picture being made as follows:

The picture taking rate, $R = \frac{1.69\ V\ F}{P\ \ H\ (1-\phi)}$ (6)

where: R = pictures per second
P = dimension of photograph along flight line, 9 inches in the case of the Panoramic Camera
F = focal length of lens, inches


OPERATIONAL ENVELOPE
OF
PANORAMIC CAMERA
FIGURE, 3000-84-3
ALTITUDE, FEET
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
500
1000
1500
2000
2500
300
25,000
$\frac{V}{H} = 0.1$

CHICAGO

The length of picture being scanner is $L = \pi F$ (7)
in which L = length of exposure, inches

Thus, L and R are related to give (5) by

$$V_f = \pi F R$$

Examination of relationship (5) at the minimum and maximum values of V over H reveal a maximum accuracy in V_f of 2% to obtain an overlap within 1% of nominal. This accuracy of overlap is well within the limits for high precision aerial photography.

The degredation of the image due to movement of an object on the ground can be analyzed by reference to Figure 3000-84-4 and the following:

Assuming a maximum tolerable image blur of 1/100 mm or .0004 inch, we can evaluate the error E allowed as

$$E\% = \frac{V_i - V_{imc}}{V_i} \times 100 \text{ per cent} \quad (8)$$

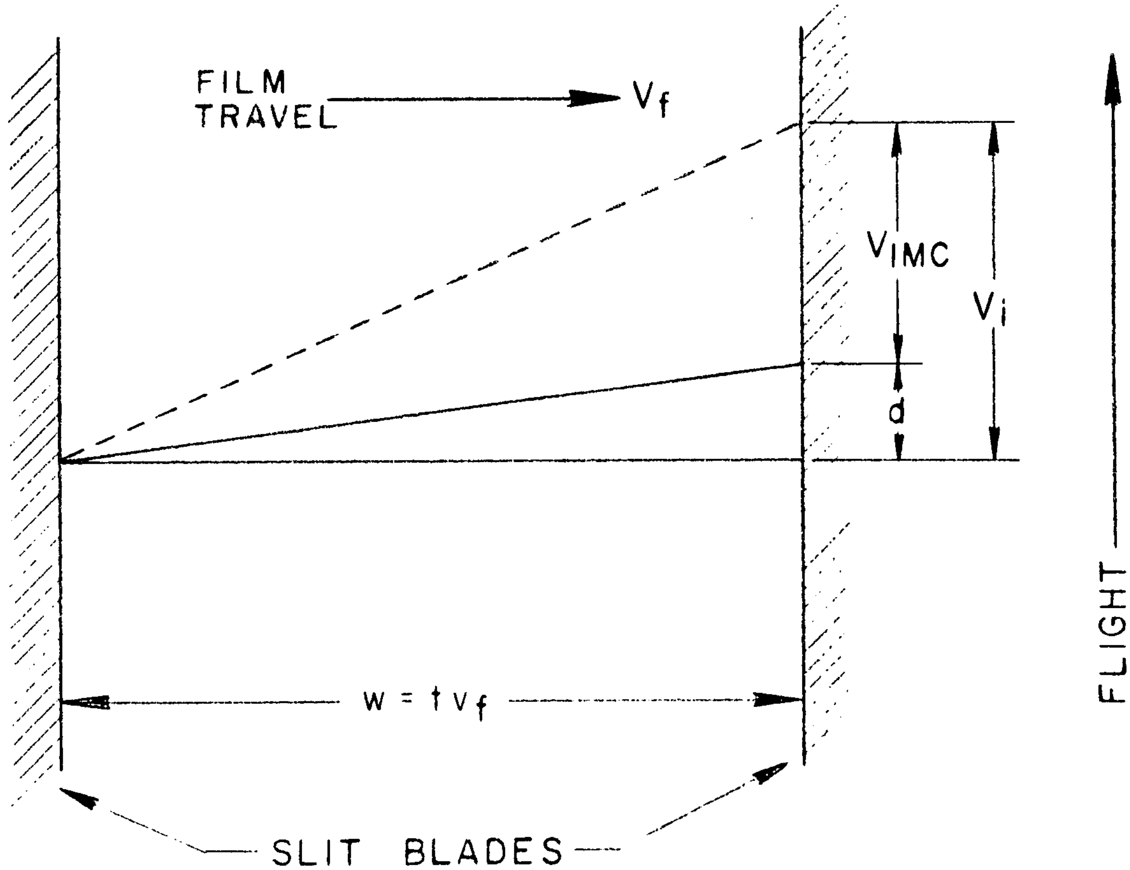
the image blur is $d = (V_i - V_{imc})\ t$

but the velocity of the image due to vehicle movement is $V_i = 1.69 \frac{V}{H} F$. Considering that $W = t_{Vf}$ and substituting the allowable blur of .0004 inch for d we have

$$E\% = \frac{0.74}{W} \quad (9)$$

This relationship for E indicates a range of permissible error of 0.75% to 37% which means that an optimum value must be chosen reflecting the most expected value of slit width, W. A value of ~~2~~% has been chosen. It will assure proper image synchronization up to a slit width of ~~.37~~ inches which will be adequate for average terrain brightness. .75

Other considerations with respect to the high quality of the velocity servo can be summed up as follows. The unit must be carefully integrated into the mechanism of the camera proper. The concepts of



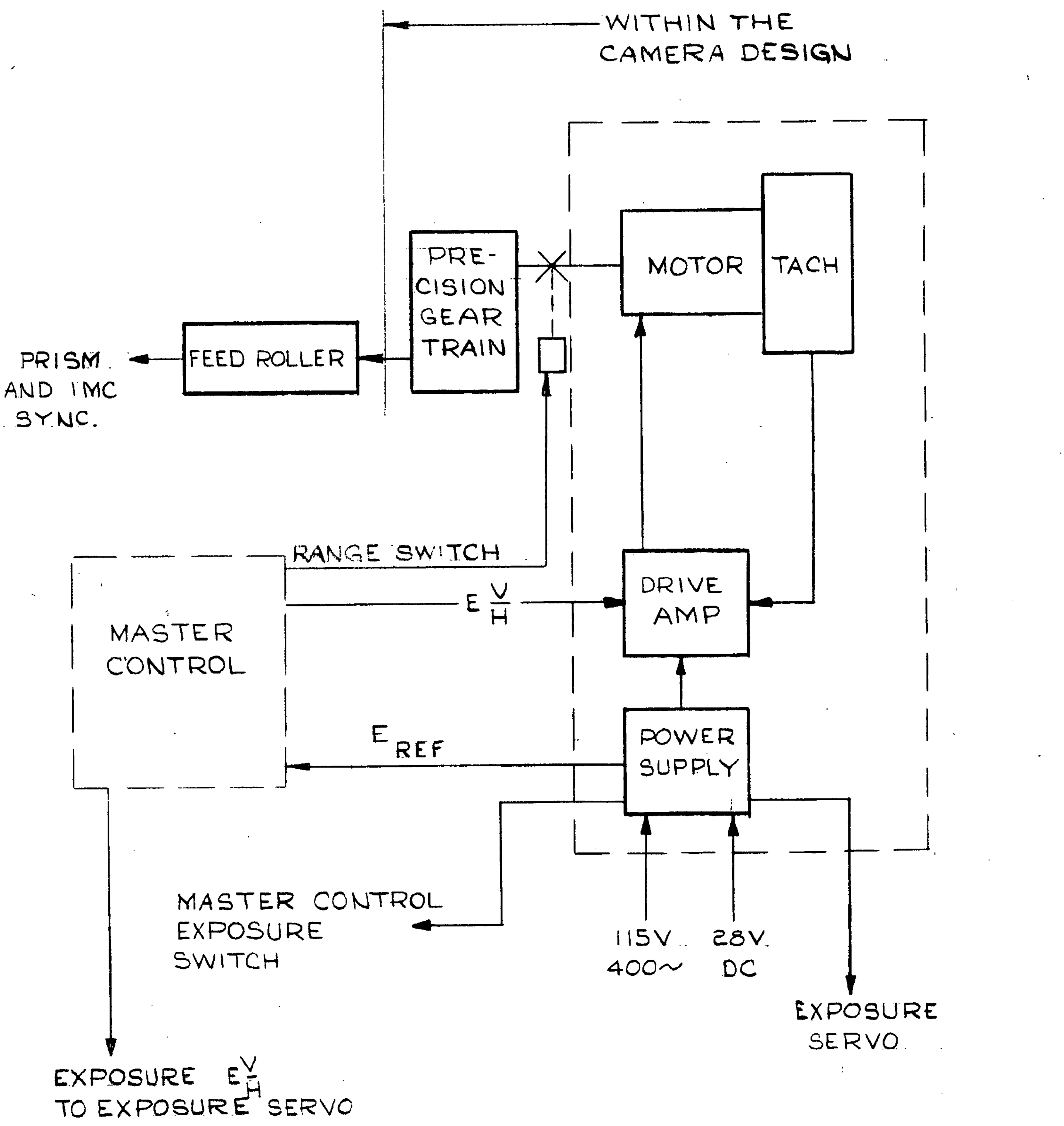
ANALYSIS OF IMC ERROR

FIGURE 4

of compact, high density, and reliable electro-mechanical design are clearly indicated: The servo must be capable of providing enough motive power to accomplish, in accordance with the design, the various mechanical functions of precise film movement across the exposure slit, lens movement for IMC, and prism drive. It is intended that the film feed and take-up power be provided by other mechanisms in the confines of the camera.

A block diagram of the proposed servo appears in Figure 3000-84-5. The completed unit, shown enclosed by the dotted line, will be contained in a package approximately 2½ x 3½ x 10 inches for the amplifier and power supply, and 2½ inch diameter x 6 inches long for the motor-tachometer. The total weight of the packaged components will be approximately 6.5 pounds. The power requirements will be 300 watts AC and 40 watts DC.

The functions of the various components are as indicated on the block diagram. A power supply will be included in the unit to provide all of the servo power requirements for both the velocity servo and the exposure servo. The velocity servo will control the rotational speed of the primary power input to the feed roller in the camera. The function of IMC and prism synchronization will be accomplished by other mechanisms in the camera.



VELOCITY SERVO
FOR
PANORAMIC CAMERA
FIGURE 3000-84-5

APPENDIX III

TECHNICAL PROPOSAL

Torquer Stabilized Camera
Mount System for
E-2 Panoramic Camera
Aeroflex Type ART-6

Refer to P-489 (P & E)

Prepared by: [redacted] STAT
Staff Engineer

24 June 1958

THE AEROFLEX CORPORATION
AEROFLEX LABORATORIES DIVISION
34-06 SKILLMAN AVENUE
LONG ISLAND CITY 1, N. Y.

INTRODUCTION

The stabilization requirements set forth in proposal request WCLR-481 requires an engineering effort in an area at the limits of the present state of the art. The Aeroflex Corporation has extensive experience in all phases of camera stabilization and feels that its experience can be successfully applied to this program.

In order to achieve the dynamic performance requirements, the stabilization problem must not be complicated by the vibrational effects inherent in conventional wrap-around gimballing or the frictional effects of large radius bearings. These limitations dictate the use of a knuckle type gimbal arrangement. The intersection of the gimbal axes has to be located at the center of gravity of the mount-camera combination. The volume about that point must allow sufficient clearance for the mount structure.

The proposed Perkin-Elmer camera design is ideally suited to the anticipated mount design. The layout of the optical system allows sufficient room for the mount within the outline dimensions of the camera body. (See Aeroflex Drawing 121-80252) The ability to accomplish the weight shift compensation for film travel within the camera, will add to compactness and weight saving.

In our experience to date on exchange of ideas and information, necessary for the preparation of this proposal, The Aeroflex Corporation feels that its mount can readily be integrated with the Perkin-Elmer camera design, producing a photographic system materially advancing the state of the art of photographic reconnaissance.

I - Description of Structure

The mount structure assembly is designed to make use of the space provided by the folded optical system of the camera. The azimuth gimbal fastens to the camera and forms a knuckle type joint with the pitch gimbal, making maximum use of the volume available within the ray angle pattern of the camera optics. The compactness of this type of construction provides good rigidity at low weight.

The roll gimbal which supports the knuckle joint passes through the body of the camera. The roll torquer mounts just adjacent to the camera body, making the total length of the roll gimbal short, helping to keep the structure lightweight and rigid.

The roll gimbal rotates in bearings set in the mount frame. The frame is mounted on vibration isolators designed to attenuate aircraft vibrations and to reduce the effects of shock. The mount frame consists of hollow castings which gives torsional rigidity and light weight.

The vertical gyro and azimuth gyro are rigidly fastened to the camera body. The mount electronics are placed on a separate shock mounted chassis. Removal of the electronics from the mount keeps the mount structure compact and at a minimum size. This arrangement allows for greater flexibility in installation.

To compensate for the change in center of gravity of the camera, due to motion of film from one spool to the other, some form of weight shift operation is necessary. The motor to accomplish this is powered by the mount electronics which sense the unbalance and apply control voltage to the weight shift motor which restores the center of gravity.

With a goal of minimum weight each part will be examined to see that it is as light as possible consistent with performance requirements.

Estimated maximum weights are 110 lbs for the mount and 30 lbs for the electronic chassis. It is estimated that the heat barrier box and pressurized electronics chassis box will weigh an additional 185 lbs.

II - Operation of the Mount (See Figure 1 - Block Diagram)

The roll and pitch position loops have the same circuitry. Only the position gains will be different due to different moments of inertia about each axis. The vertical reference is an ARX-3 Vertical Gyro. The gyro is slaved to a two axis pendulum assembly through its own erection system. The pendulum error voltage drives the erection amplifier which causes the gyro torquers to move the gyro gimbals to correspond with the pendulum position. The gyro output is in the form of D. C. signals with a scale factor of 133 m.v. /minute.

In the operation of the normal erection system of the ARX-3 Vertical Gyro, the erection rate is 2 degrees per minute. This represents 120 seconds or in a 1/50 second exposure, 2.4 seconds of arc. The maximum allowable motion in this time is 3.0 seconds (Paragraph 3.4.13.1, Exhibit WCLR-481). Thus 80 percent of the allowable steadiness margin would be used up with normal erection system. This would preclude the use of such a system and require an integrating erection system to be able to meet performance requirements.

An integrating erection system acts as a low pass filter. Accelerations caused by the normal yaw frequencies of the aircraft will be filtered out, increasing the steadiness capability. Constant velocity motions such as gyro free drift, earth rate and earth profile effects will not cause verticality errors.

The D. C. output signals of the gyro drive the mount gimbals through the torquer amplifier and the torquers.

Film motion from the supply to the take-up spools will cause an unbalance in the roll axis. The unbalance will produce a differential torquer current. The weight shift amplifier operating on this signal drives the weight shift motor, which is located in the camera, to correct the unbalance.

In azimuth, the mount is slaved to a synchro in the camera system control box providing drift information. The azimuth error signal is amplified to drive the torquer of a HIG-4 single axis gyro. The gyro signal operator drives the azimuth torquer through the azimuth torquer amplifier. The gyro will tend to keep the camera still in space. The gains are so adjusted that the HIG signal dominates, providing the steadiness required.

If the aircraft executes a turn and remains in the turn for a considerable period of time, the centrifugal component of acceleration acting on the gyro pendulum would drive the gyro off vertical. For this reason, the gyro erection is cut off when the mount rests in the roll stops. This permits more rapid recovery of the mount at the completion of the turn.

The roll stops are also used to change the gain of the azimuth loop during a turn in order to have the drift signal dominate. This will leave the mount aligned with the ground track at the end of the maneuver.

The power and control unit provides all the necessary reference voltages, time delays, and switching for mount operation.

A caging mechanism prevents motion of the camera when mount power is off. This protects the equipment against damage due to large angular accelerations.

III - Thermal Barrier

For the extreme temperature conditions of paragraph 3.8.1 of Exhibit WCLR-481 (300°F and -100°F at 100,000 feet), a heat barrier box will be built to enclose the mount and camera. Cooling will be accomplished by circulation of a water-glycol solution through tubing on or in the walls of the barrier box. Coolant carrying tubing will be used to cool critical areas of the mount such as the gyros and the torquers.

The cooled box is placed inside another box making a double-walled unit. The space between is filled with fibre glass or other suitable insulation. Mechanical and electrical connections are made in such a manner as to allow no unbroken heat paths to the outside atmosphere.

When in the box the isolators are removed from the mount and the mount is rigidly fastened to the box. The box is then mounted in the aircraft on suitable vibration isolators.

A flexible duct type connection will be run to the frame of the window in the skin of the aircraft. It is preferable that the window frame be made of some non-heat conducting material.

The electronic packages will be mounted in a similar type box except that this unit will be pressurized and kept at sea level to permit air circulation to transfer heat from the components to the box walls.

Under conditions of extreme cold (-100°F) the coolant fluid kept at approximately 120°F will keep the equipment at proper operating temperatures and the barrier boxes will serve as heat retainers.

IV - Specification Comments

3.2.2. Should read "with the exception in 3.2.1....."

3.4.13.4 Contract number should read AF 33(038)19825.

3.4.13.9 Add "or equal" to the end of the first sentence.

3.8.1 Should read ".....the camera and mount....."

i. Subsequent to shock - 7.5 g's

j. Subsequent to acceleration - 4 g's

4.1.4.2. (2) Should read ".....room pressure and the temperature shall be 0°F).

4.1.4.2.(4) Should read "Vibration - In accordance with procedure I of MIL-B-005272B."

4.1.3.5 No commercial equipment is available to vibrate below 5 cps. Figure 1 does not go below 5 cps., therefore, this should read".....For all frequencies between 5 and 50 cps....."

V - Factors Assumed in Preparation of Proposal

The heat barrier box does not include design of the window. Because of the optical problems involved, it is felt that responsibility for design of the window should remain with the camera manufacturer. Close liaison will insure proper connection between the heat barrier box and the window frame and also insure proper window size for the ray angle patterns involved.

The qualification test program and other in-plant testing at Aeroflex assumes that a dummy camera with the same weight, center of gravity location and dimensions critical as to fit, will be made available by the camera manufacturer ten (10) months after award of the contract.

Although mount caging is not specifically called for in the exhibit, it is deemed necessary to protect the equipment against damage. A caging mechanism designed for greatest simplicity and minimum weight would lock the camera to the mount frame. This method requires a caging pin located on the camera body.

The compact structure of the mount makes it necessary to provide a mounting platform for the vertical gyro on the camera body.

The weight shifting to compensate for center of gravity shift due to film motion will be accomplished by the camera manufacturer, with advice from Aeroflex as to type of motor and gear ratio.

Drawings supplied will be manufacturer's shop drawings in accordance with paragraph 3.12.2 of Exhibit WCLR-481.

The reliability program will be formulated within the following policy outline:

1. Translate reliability requirements into quantitative design parameters.
2. Design for optimum requirements.
3. Maintain organizational responsibility for implementing reliability.
4. Promote standardization which contributes to improved reliability.
5. Accomplish testing to measure and improve reliability.
6. Coordinate data collection and feedback.
7. Promote reliability programs by sub-contractors and suppliers.
8. Keep abreast of and cooperate in Government and industry reliability efforts.

At present the general configuration of the system is known and a prediction of the system reliability will be made on the best available data of the parts to be used. However, in a realistic and practical sense, this prediction phase cannot be expected to stand alone as a measure of system reliability. This is so since all parts do not have failure rate data though they may be the best available.

In addition, data available applies to the specific component alone and does not necessarily consider the component in the context of a complete design or with the exact environmental conditions specified for this equipment. Furthermore, the small number of components used cannot be considered in terms of a random sample. Thus, failure rate data which is based on large numbers requires certain qualifying assumptions to be applied to reliability calculations.

The assumption includes the effect of how the component is used and the environment it must endure. Handling in terms of production, shipping, storage and use is also a factor. To account for these variations over laboratory conditions, a factor of 1/2 to 1/3 the mean time to failure is a useful assumption.

In addition to indicating a theoretical goal of reliability, another useful purpose of this phase would be to ascertain the effect of any component that grossly degrades the reliability merely by the fact that it is used. A good example would be the use of vacuum tubes. Failure rates of tubes run considerably higher than resistors or condensers for example. High tube failure rates would have a dominating effect on degrading reliability. The use of transistors instead of vacuum tubes brings the failure rate down to a less dominating value.

In terms of the single piece of equipment being furnished, the greatest care must be taken in the design stage to ensure the best possible results within the limited statistical validity of the reliability study.

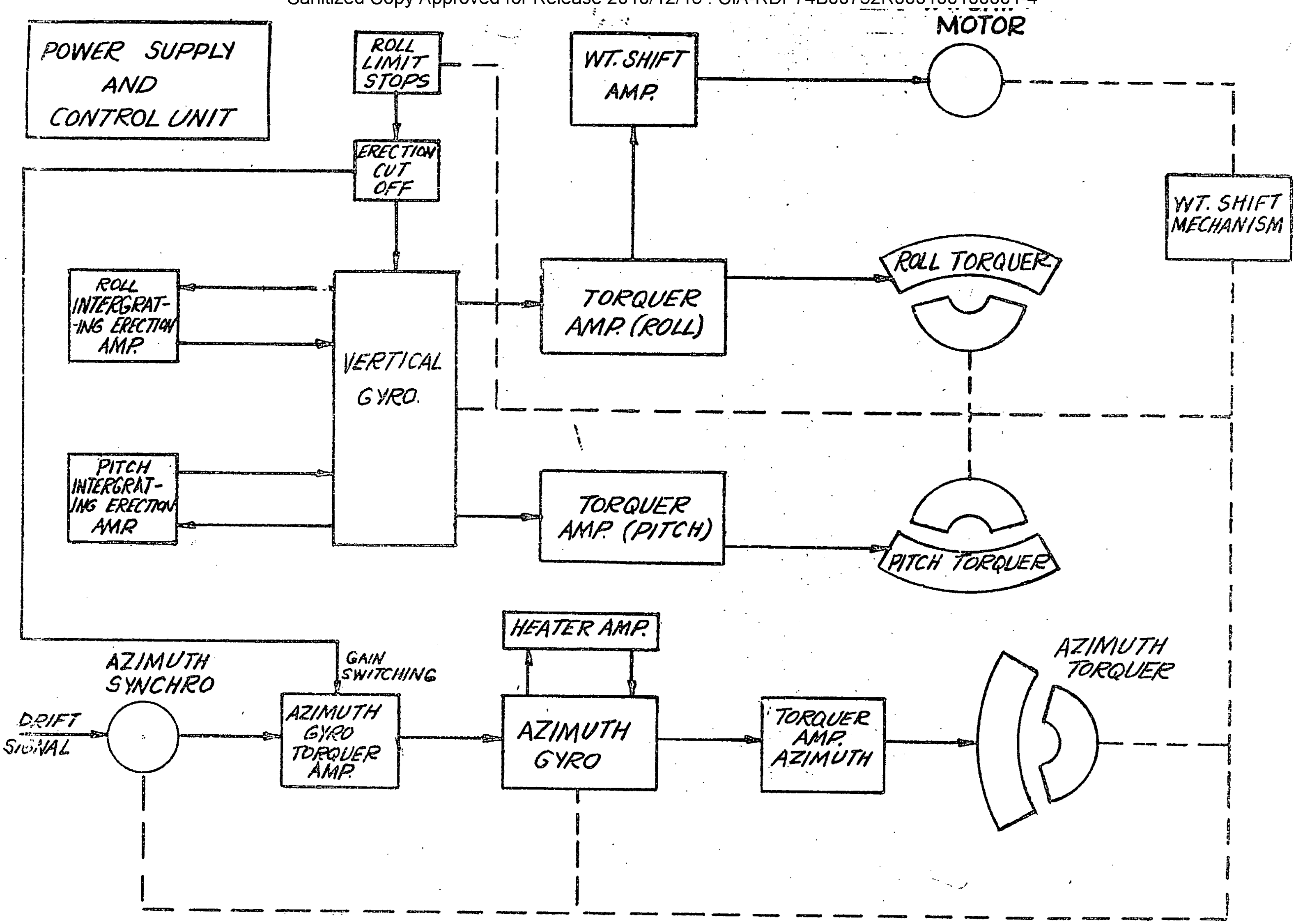


FIG - 1

AEROFLEX
ART-6 TORQUER MOUNT
BLOCK DIAGRAM

PROPOSED PROJECT PLAN - 24" PANORAMIC CAMERA.

PROPOSAL # 2324

THE PERKIN-ELMER CORP. NORWALK CONN.

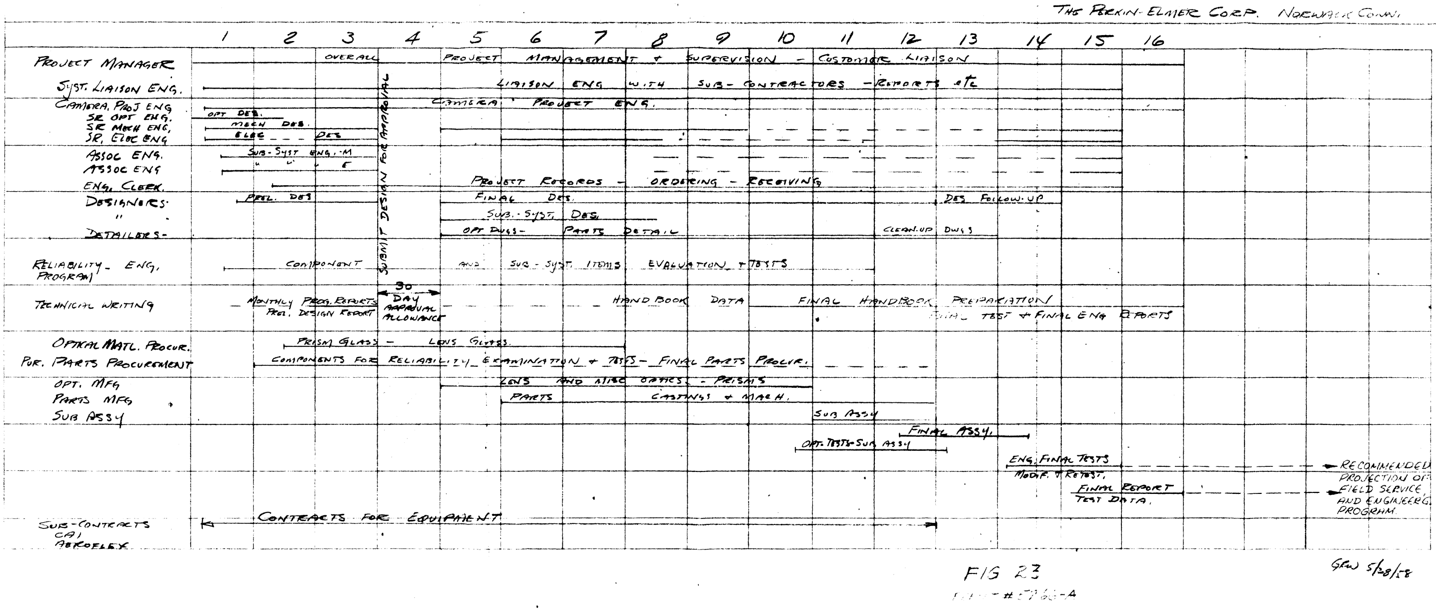
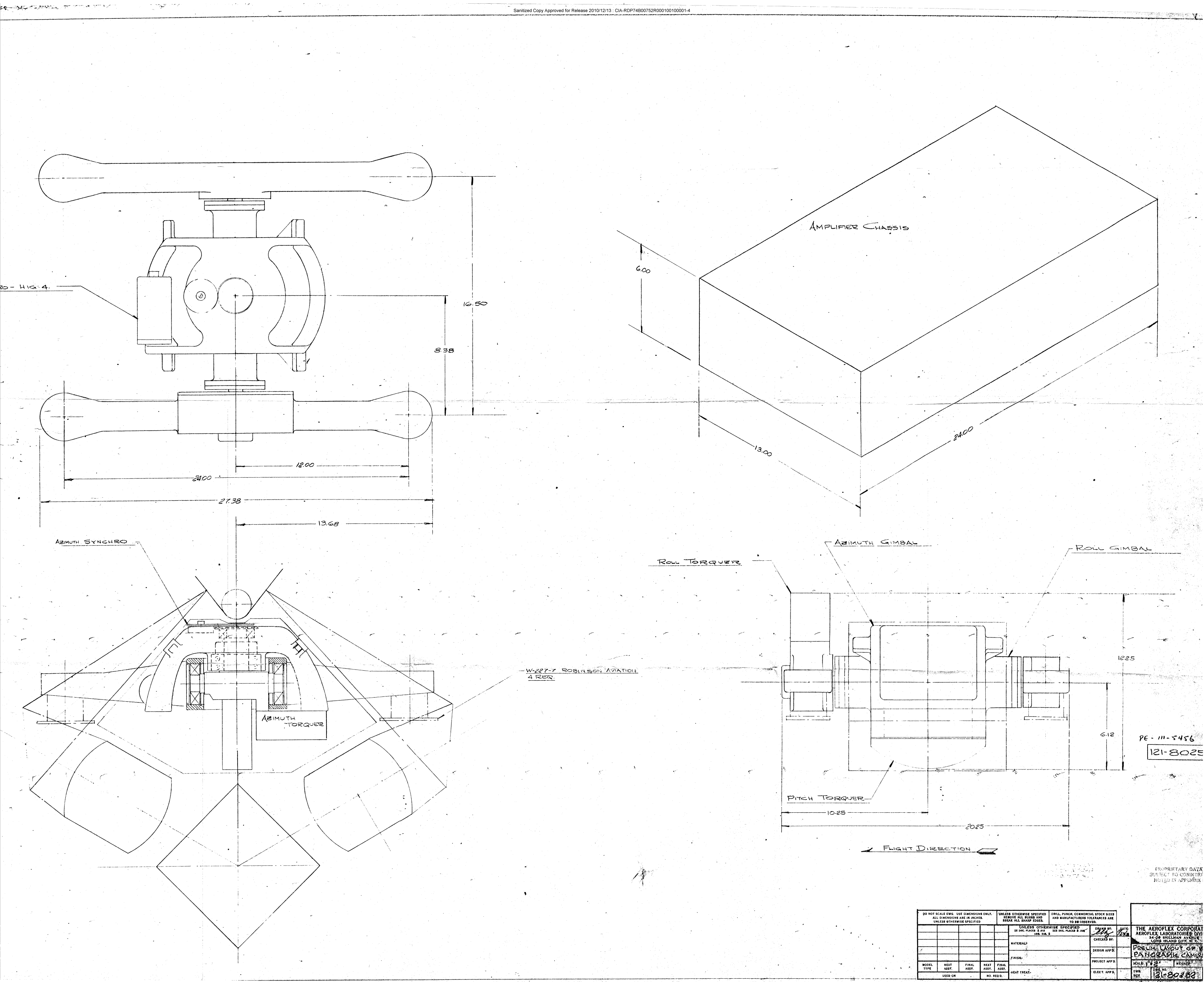


FIG 23

GEW 5/28/58

#5763-4



AMPLIFIER CHASSIS
6.00
13.00
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AZIMUTH SYNCHRO
W-227-7 ROBINSON AVIATION
4 REQ
AZIMUTH TORQUER
ROLL TORQUER
AZIMUTH GIMBAL
ROLL GIMBAL
12.25
6.12
PITCH TORQUER
10.25
20.25
FLIGHT DIRECTION
PE-111-5456
121-8025
PROPRIETARY DATA
SUBJECT TO CONDITIO
NOTED IN APPENDIX
DO NOT SCALE DWG. USE DIMENSIONS ONLY. ALL DIMENSIONS ARE IN INCHES. UNLESS OTHERWISE SPECIFIED
UNLESS OTHERWISE SPECIFIED REMOVE ALL BURRS AND BREAK ALL SHARP EDGES.
DRILL, PUNCH, COMMERCIAL STOCK SIZES AND MANUFACTURERS TOLERANCES ARE TO BE OBSERVED.
UNLESS OTHERWISE SPECIFIED
MATERIAL:
FINISH:-
HEAT TREAT:-
MODEL TYPE
NEXT ASSY.
FINAL ASSY.
NEXT ASSY.
FINAL ASSY.
USED ON
NO. REQ'D.
DRAWN BY:
DATE:
CHECKED BY:
DESIGN APP'D.
PROJECT APP'D.
ELEC'T. APP'D.
THE AEROFLEX CORPORAT
AEROFLEX LABORATORIES DIVI
34-06 SKILLMAN AVENUE
LONG ISLAND CITY, N. Y.
PRELIM. LAYOUT OF
PANORAMIC CAMER
SCALE 1"=2"
WEIGHT
DWG. SIZE
DWG. NO.
121-80252
PE-111-5456